SPE JOURNAL

VOL. 17 NO. 4 APRIL 1961

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BEGINNING ON PAGE — 340

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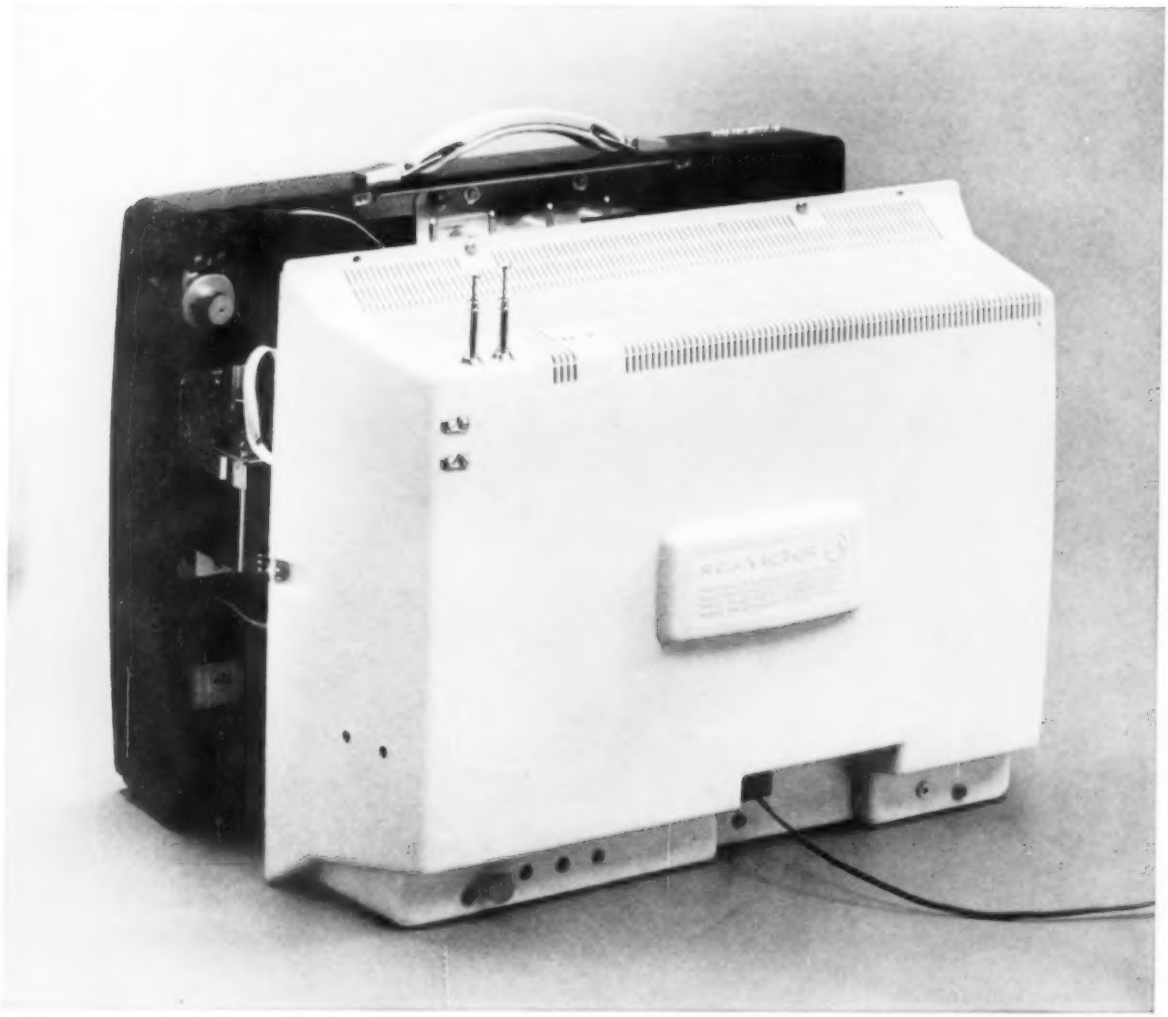

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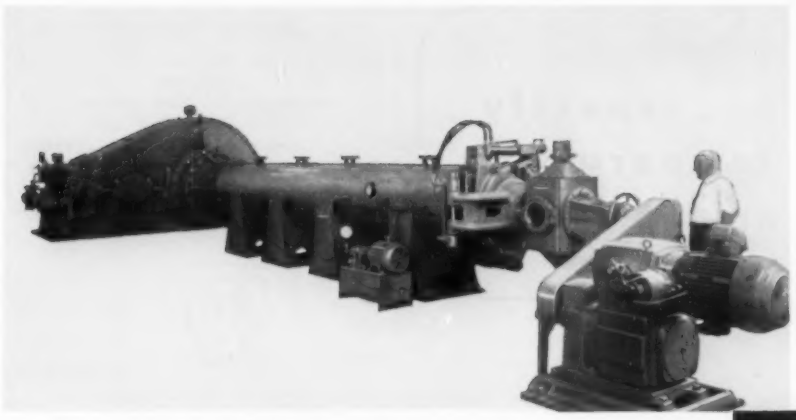
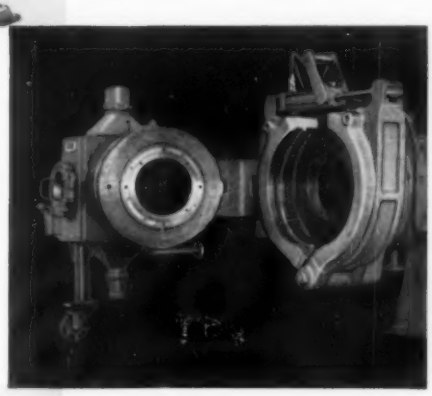


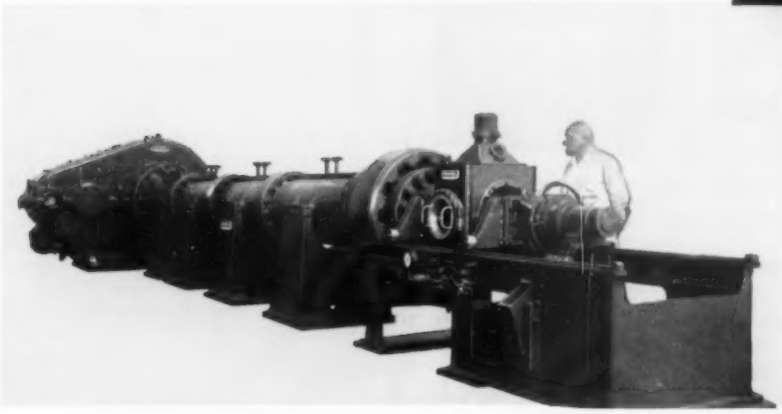
The machine at left is one of the largest underwater pelletizers ever built. Equipped with a 15" screw that is 30' long, it is driven by a 2000-hp motor and is designed for 10,000-psi working pressure. The head (shown open in the illustration below) is equipped with a hydraulic-clamp locking device.



Two examples of

underwater pelletizers

developed by Farrel for high-capacity extrusion



This cold-feed polyethylene extruder is driven by a 1500-hp motor and Dynamatic drive with a top speed of 100 rpm. Designed for head pressures of 10,000 psi, it is equipped with a long throttling ring. The head is mounted on rails so that after unlocking it can be quickly withdrawn.

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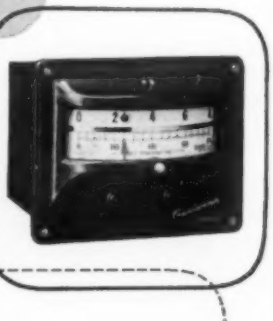

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SPE JOURNAL
VOL. 17 • NO. 4
APRIL 1961

COVER: Each year, the SPE Journal publishes the top technical papers presented at its Annual Technical Conference. This issue, as our artist's "stamp" indicates, is the Best of ANTEC issue.

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Single molding has red lens section, clear housing
On the 1961 Lark—Housing and lens are a one-piece Plexiglas molding!
In finished part, clear housing is metallized on second surface; small side-jewel section is sprayed red

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EDITORIAL

Scientific Advancement of Plastics Engineering — Cause and Effect of Growth of SPE Membership

Looking at a molded plastic item, it is difficult to comprehend such an item being a complex synthetic product. But consider the definition of the word plastic: A material that contains, as an essential ingredient, an organic substance, of large molecular weight, solid in its finished state, and at some stage in its manufacture or processing into finished articles, can be shaped by flow. Here, brought into sharp focus, are the various elements fundamental to plastics.

When one reflects further upon the scientific disciplines implicit in the above definition, it becomes clear that there is a vast store of chemistry and engineering behind the molding of a single plastic part. There is also the realization that there must be a nurturing of cooperation and respect between the many disciplines before molding machines can work their magic. And herein lies the biggest potential for growth of membership in SPE. What better vehicle is there to foster the necessary interdisciplinary respect than the Society? At once, advancing technology of plastics engineering becomes the cause and effect of increasing SPE membership.

The Society was originally founded to "effect any betterment pertaining to the designing, styling, and promotion of the use of plastics." But as the industry grew, so did the technology. With the change in technology came also a change in motivating purpose of the Society and the original objective was changed to "promote scientific and engineering knowledge relating to plastics." In a sense, it was a coming of age. No longer was the membership limited to sales and processing people. Now there were mechanical engineers who designed and built machines. There were chemists who cajoled single molecules into forming new long chain polymers. And there were chemical engineers who designed and built the plants for making the new polymers. The addition of members and multiplication of interests is still going on.

Today, because of the breadth of our technical interests, we have divided them into various Professional Activity Groups, ranging from Polymer Structures to Plastics in Buildings. As we increase our membership and shape our growth, these will be divided into more restrictive fields.

Men and organizations exist to fulfill a purpose. Maybe through some such magic as a polymerization process, membership in a scientific Society provides an atmosphere in which men of ordinary stature are able to exhibit extraordinary performance.

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Body and legs of Madame Alexander 36" nurse doll (A) and 15" Cathy doll (B) blow-molded of Bakelite Brand high density polyethylene for Alexander Dolls, Inc., New York, N. Y. Ring (C) and bead (D) sets and wheels for toy racer (E) blow-molded of low density polyethylene by Fisher-Price Toys, Inc., East Aurora, N. Y.

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Letters

Publishing Idea for SPE

Dear Sir:

I have recently learned that an American publisher of technical books has had some of these books reprinted in Japan (in English). The resulting low price enables their distribution in the Far East (Japan, Indian, Indonesia) at retail prices that the Asian students and engineers can afford. This action has value as a form of technical assistance, in addition to its business aspects.

The SPE ANTEC and RETEC papers (preprint books) would be an ideal subject for such a venture. They could be divided into rather small inexpensive practical volumes—each covering a specific area such as decorating, extrusion, blow molding, etc. I am accordingly passing this idea along to you, and would be glad to assist further in its development.

A. L. Griff
Technical Service Dept.
Union Carbide Plastics Co.

Editor's Note

Reply was made to Mr. Griff by Dr. Alex Sacher, Chairman of SPE's Publications Committee. Dr. Sacher indicated that the Publications Committee will investigate the possibility of moving in this direction.

Rebuttal

Dear Sir:

I read with absolute disbelief the letter of Mr. Morse in the February issue of the SPE Journal. It doesn't seem possible that anyone reading the Journal month after month could avoid the many articles covering the practical approaches to many plastic problems. These articles cover many different subjects, and certainly are as general in interest as they can be.

Many of us are busy, and have little time to digest, in detail, the huge mass of literature produced each month. It might be a good thought for Mr. Morse to look back at his past copies of the SPE Journal and count the number of very interesting "general interest" articles, which he failed to notice. The SPE Journal has a specific function in the plastics industry, and I feel it is doing a good job of meeting that function.

Milton A. Sanders, President
Precision Molding Inc.

Interest in Extrusion

Dear Sir:

We greatly appreciated the article in the February 1961 issue entitled: Extrusion of Sheet from High Density Polyolefins. Is is possible to obtain six reprints?

J. P. Pritchard
Ass't General Manager
G. M. Plastic Corporation

Status Change

Dear Sir:

Please consider this letter a request for a classification change in my listing in the SPE Roster (published annually in the August issue of the SPE Journal). My objection is the "Associate Member" designation.

By way of substantiation, let me give you a little background. Since I am the only plastics engineer, or even technician between Seattle, Wash. and Minneapolis, Minn., (an area comprising half the Atlantic Seaboard), my work is, of necessity, far different from that of your membership generally. I envision the day when we will have sharply defined plastics operations such as now exist in the East, but, in the meantime, I must be all things to all men.

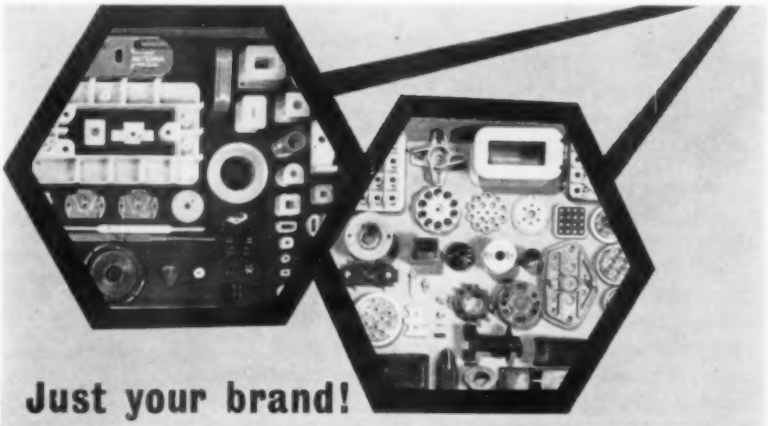
I question that it is generally realized in the East that there are cities the size of Spokane (about 250,000) without even a source of polyester sheet other than the corrugated patio cover set. I am that source only because there is no one else. For these services I am largely unreimbursed, but I feel that I do prevent a great amount of misuse of materials, misrepresentation, and "miracle product" propaganda. By listing me as a sales representative you place me in the same category with every semi-literate huckster of toys on the West Coast.

Please consult the attached letterheads, and give me the status of a full membership.

Robert J. Owen
Spokane, Wash.

Editor's Note

This letter was published because we feel that the question of status, in any industry, is important to the people working in that industry. Indeed, one need only refer to a recent survey (CHEMICAL AND ENGINEERING NEWS, March 13, 1961 page 78) to see how members of one industry—the chemical industry—feel about professional status. In response to his letter, the Society has sent the proper forms to Mr. Owen to enable him to apply for Senior membership in the Society. Also, members of the Society may be listed in the Roster with any title they so indicate.



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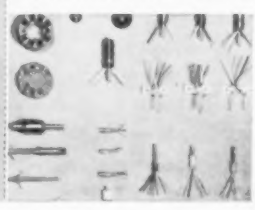


What do you think of Overseas Operations by WEST*?

This recent news item, referring to our British subsidiary, brought us considerable comment. We take this means of answering any queries that were not expressed directly to us.

GOOD CITIZEN?

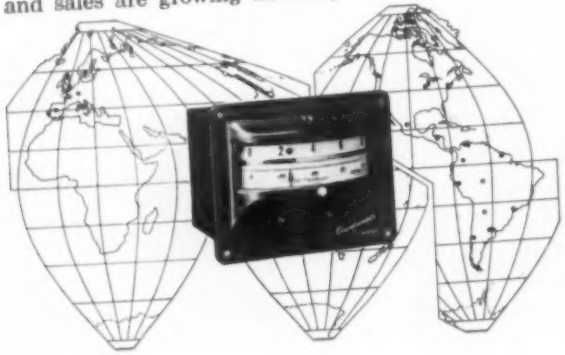
Building this British subsidiary did *not* involve a "flight of capital" nor using-low-foreign-costs-to-undermine-the-home-market. Our seed-money did not exceed the price of a few automobiles; we supplied mainly know-how and American-made components. Far from "exporting gold," this enterprise sends home dollars from otherwise inaccessible sources. And, its products are *not* sold in the U.S.A.

GOOD SERVICE?

From parts to complete instruments and control systems, a given West unit made in the U.S.A. is interchangeable with its counterpart made in England (or in our other subsidiaries developing abroad). Add our world-network of West offices, carrying stock and kept current on all types of applications, and you can rely on prompt service . . . *wherever* you are situated.

GOOD BUSINESS?

Our products are designed to serve under industrial conditions found *anywhere*, with minimum maintenance. This factor plus our world-wide service offers real advantage for direct users and for makers of machines incorporating temperature control . . . wherever they buy or wherever their installation is located. One gauge of our "foreign policy" is our U. S. production; our payroll, facilities purchases and sales are growing annually.



CHICAGO DAILY TRIBUNE:
TUESDAY, JANUARY 17, 1961

CHICAGOANS' 5 YEAR BRITISH VENTURE PAYS

West Instrument Now 2d Biggest in Field

BY ARTHUR VEYSEY
[Chicago Tribune Press Service]

LONDON, Jan. 16—Five years ago last October, Richard West came to England to see if there was any market for the temperature controls developed by his family's Chicago company, West Instrument corporation.

West decided the market was here. The problem was how to enter it.

He advertised for a British heat control engineer. Among the applicants was James Hartnett. West hired him, went back home, and shipped over parts for some of the Chicago designed equipment.

Begins in Back Room

Hartnett assembled the parts in a back room of a London house and sold them. Within six months, the "assembly plant" outgrew the room. Hartnett rented part of a former warehouse in Brighton, a seaside town usually thought of as a resort.

Hartnett went into British laboratories and sought out young university trained engineers. Soon they were traveling to the continent and British overseas areas. Only North and South America were reserved as Chicago domain.

Next, components were ordered from British and continental firms.

Quantity, Value, Rise

Last year the output of the Brighton plant went up 77 per cent in quantity and more than 100 per cent in value. This year the increase in quantity is running 79 per cent more than last year and in value quite a bit more than 100 per cent.

West Instrument, Ltd., plans to build a new factory next year. The British staff numbers 70, with branch offices in London, Cardiff, Manchester, Newcastle, Scotland, France, and Germany, and a corps of agents elsewhere in Europe, Asia and Australia.

West has found its biggest opportunities in the plastic, nuclear energy and highly specialist metallurgical field, where accurate temperature controls are vital. West controls are designed to maintain a chosen temperature within ¼ of 1 degree.

Brother Takes Over

Richard West was killed in a plane accident two years ago. His brother, William, succeeded him as president of the Chicago company and of the wholly-owned British subsidiary. British earned profits have been put back into the subsidiary.

The British operation has given two advantages to the parent company. Its representatives and agents service Chicago made controls in American exported industrial plants over much of the world. And British representatives, working closely with industry and research, are improving and expanding design and uses.

After five years, with very little capital flown from Chicago, West ranks second biggest in the British temperature controls field.

YOU ARE INVITED TO RAISE ANY QUESTIONS WITH YOUR WEST REPRESENTATIVE (LISTED IN THE YELLOW PAGES) OR TO WRITE DIRECTLY.

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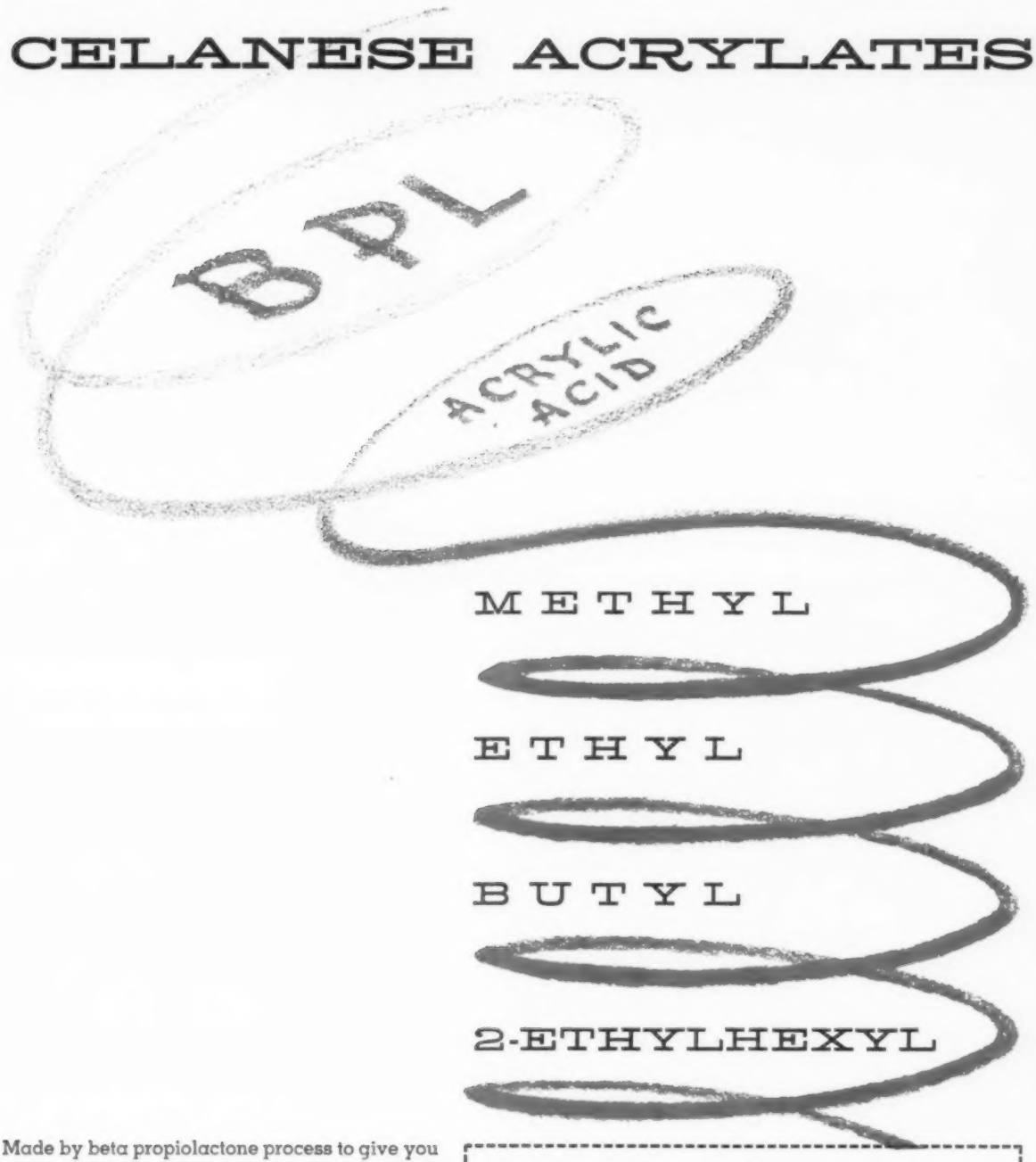

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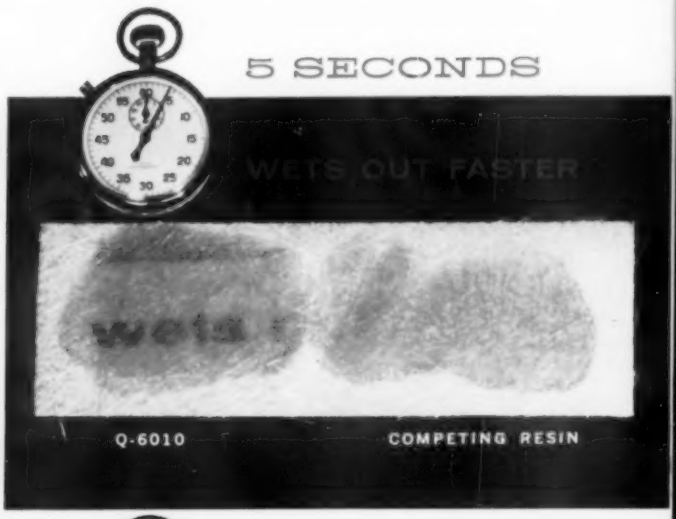

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SPE JOURNAL NEWSLETTER

reading time
1 minute

Screw Molding Pros and Cons

Screw type vs plunger injection molding is currently a hot subject in plastics processing. The article by Swiss authors on page 331, this issue, outlines in fair detail the virtues of screw type injection molding. However, some of the reported disadvantages are: The screw does not revolve continuously in many designs, cutting down plasticizing efficiency, nozzle valves are now too complicated, and large variations exist in wattage, screw size, and screw length.

More Polypropylene

Texas Eastman Company, a manufacturing division of Eastman Kodak Company, announced recently it is a major producer of polypropylene with a 20 million pound plant at Longview, Texas. Eastman's polypropylene is being made by a continuous process and under a relatively low pressure. Polypropylene production is variously estimated to reach 460 million pounds by the end of 1962.

Foamed Hut

The construction of shelters offers promise of a new application of sprayed-on urethane foam. The method, now experimental, involves spraying rigid urethane foam over an inflated film, then deflating and removing the film after the foam has set. Doors and windows can be cut out with a saw. Foam huts in any shape or form can be made in this way. Advantages: Speed of erection, lightness, and superior insulation. A quonset hut 45 feet long, 20 feet wide, and 10 feet high was built by this spray technique in three hours by three men.

Aluminum Wool

Interest is increasing in the use of aluminum wool as a thermally conductive medium in the fabrication of polyester and epoxy press tools, foundry patterns, and matched die molds. The wool helps dissipate the exothermic heat generated during the setting of the resin and it renders the final product as heat conductive as metal. So far, development work is being pressed only in England.

New Method Studies Degradation

Two Russian chemists have developed a method for measuring the heat resistance of polymers based on measuring changes in the modulus of elasticity. They report that the method allows close inspection of changes in thermosetting resins, connected with structural changes in the polymer structure leading to variations in density and shrinkage (SPE TRANSACTIONS, April, 1961). On studies of laminated materials, the effect of the reinforcement was minimized, paving the way for development of more heat resistant-resin.

new technical ideas • trends • industry news

WHAT'S NEWS IN ENJAY TECHNICAL SERVICE

Enjay helps reduce cost of 90°C vinyl wire insulation...

An important part of Enjay Technical Service is developing useful new products that reduce costs, yet maintain performance. Ditridecyl phthalate for use in plasticizing vinyl wire insulation is a good example of this research activity. By tests, such as the oven aging shown above, Enjay was able to prove that DTDP, made from Enjay tridecyl alcohol, performs as an efficient, non-volatile plasticizer for 90°C wire — yet reduces plasticizer cost.

Test results, at right, show that the insulation exceeds the U.L. Specifications.

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	U.L. Specification Minimum	DTDP Plasticizer
Elongation	65% retention	100% retention
Tensile Strength	65% retention	101% retention
Dielectric Strength	50% retention	127% retention
Insulation Resistance*	.01 megohm based on 1000 ft.	0.36 megohm based on 1000 ft.

* 1 day and 7 days @ 113°C.

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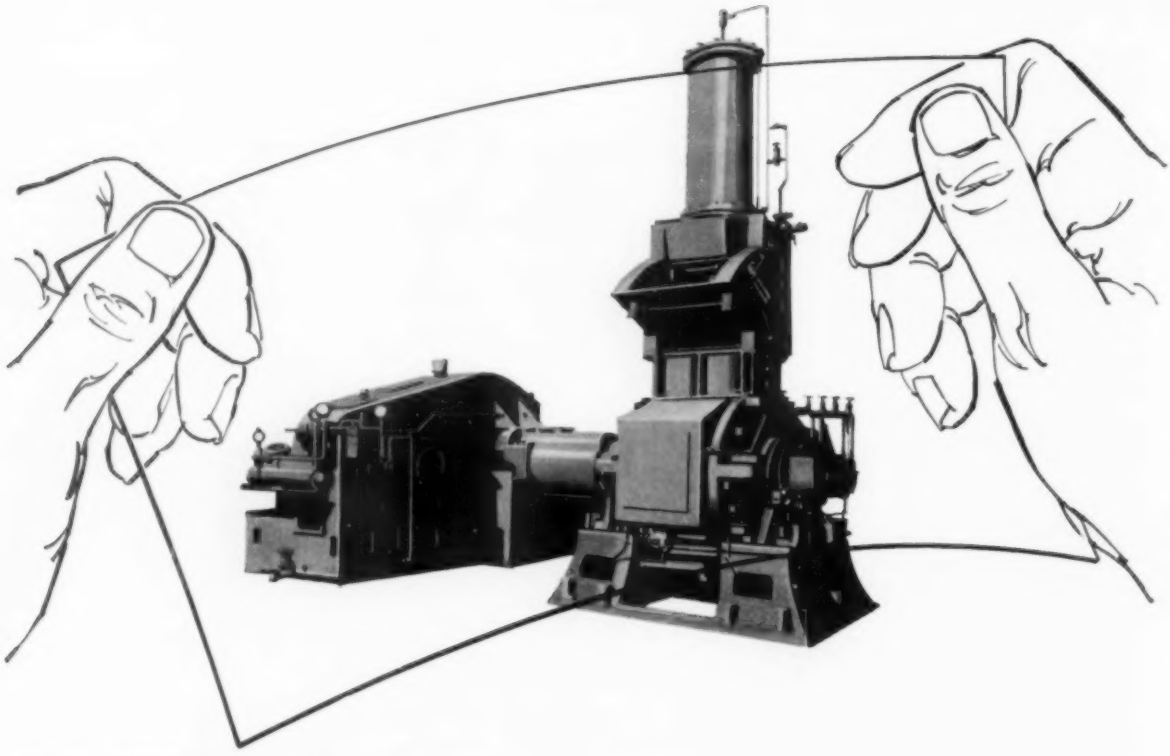

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GRACE PLASTICS

Plastics in Automobiles Subject of Detroit Meeting

To highlight the ever increasing use of plastics in automobiles the Detroit Section of the Society of Plastics Engineers will sponsor on May 9 a Regional Technical Conference on "Plastics for the Automotive Industry." This Conference, to be held at the Rackham Educational Memorial, will feature discussions by prominent automotive engineers and plastics processors and finishers on new plastics developments, applications and trends in the automobile industry.

Included in the technical program are papers on specification, testing and decoration of plastics as well as discussions of specific applications, historical development and automotive industry attitude toward plastics materials. This program, developed with the cooperation of SPE's Plastics in the Automotive Industry Professional Activity Group, will also feature luncheon addresses by Maurice F. Malone, SPE International Secretary, and Robert F. McLean of General Motors Corp. who will discuss "The Autoline—and Plastics."

Registration fee for the meeting (excluding luncheon) is $2.50 for both members and non-members of SPE. Advance registrations should be directed to:

John D. Cochrane, *Registration Chairman*
Hercules Powder Co.
1900 Fisher Bldg., Detroit 2, Michigan

The complete technical program announced by Program Chairman, Richard E. Powell of Rohm & Haas Co. follows:

PLASTICS FOR THE AUTOMOTIVE INDUSTRY

May 9, 1961
Rackham Educational Memorial
100 Farnsworth Avenue, Detroit, Michigan

8:30 A.M.—Registration

9:30 A. M.—Morning Session

Specifying Plastics for Instrument Panels
Henry C. Stuerzl, *Staff Engineer*, AC Spark Plug Div. General Motors Corp.
A general discussion of the techniques of specification for plastics materials in instrument cluster applications.

Polyester and Premix Parts in Automotive Applications
James Greig, *Chief Engineer*, Woodall Industries
The speaker will develop an explanation of the use and reasons for using polyester and premix materials for automotive parts.

Development and Growth of Decorated Plastics in the Automotive Industry
Milton Z. Thorson, *Vice President*, Red Spot Paint and Varnish Co.
This discussion of coating systems and plastics decorating techniques will be supplemented with a display of Florida panels indicating some of the problems of evaluation inherent in first and second surface work.

Discussion
A panel comprising speakers of the morning session will answer questions.

12:00 Noon—Luncheon

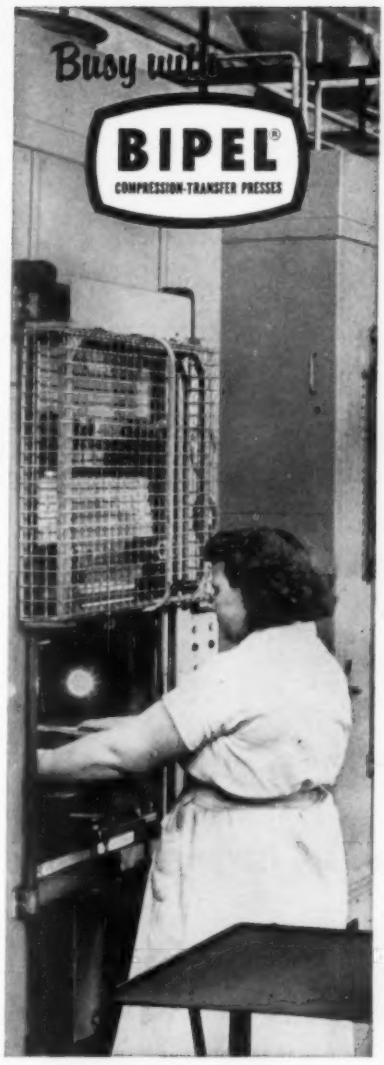
The Autoline—and Plastics
Robert F. McLean, Automotive Research Design, General Motors Corp.
Maurice F. Malone, Secretary, Society of Plastics Engineers

1:30 P. M.—Afternoon Session

Historical Background of Plastics at Ford Motor Company
John Mickey, *Engineer*, Adhesives and Plastics, Non-Metallic Sec., Ford Motor Co.
This presentation will be concerned with the history and development of plastics at the Ford Motor Co., profusely illustrated with slides.

Specification and Testing of Plastics at Chrysler Motors
W. J. Simpson, *Manager*
Rubber and Plastics Laboratory, Cent. Eng. Div., Chrysler Corp.
Discussions of selection and specification of plastics materials at Chrysler Motors.

Important Considerations of Molding Applications in the Automobile
Robert Giles, *Manager*, Plastics Res. and Dev. Laboratory, American Motors Corp.
The engineer looks at the plastics industry through a stimulating commentary on the efforts and developments of the plastics industry.



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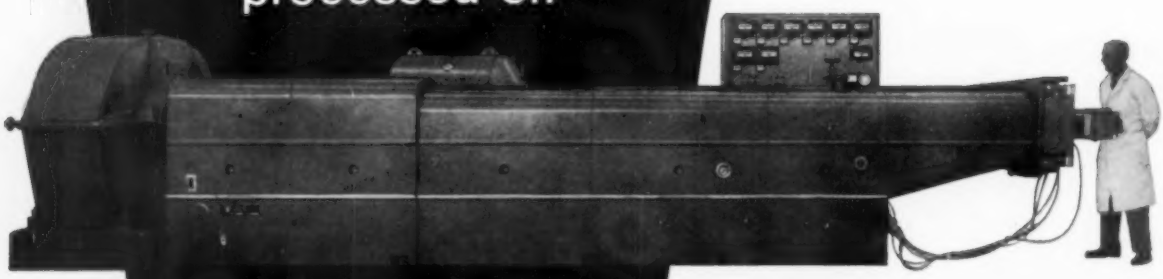

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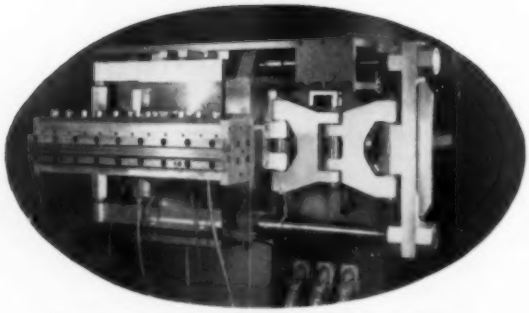

Photo above shows quick-opening pneumatic toggle clamp gate

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SPEAKING OF EXTRUSION

Trends and Needs in Extruder Design

Over the last several years, the single screw extruder has been analyzed mathematically, experimentally and visually from many points of view. It has also been enlarged, lengthened, instrumented and modified in many ways to accomplish specific purposes with a high degree of mechanical and thermal efficiency. Its performance characteristics are generally understood and many of its idiosyncracies are well known. By-and-large, it is recognized as a device which combines the functions of melting and homogenizing polymers through effective use of frictional working and transferred heat and developing the necessary pressure for forming a finished article on a continuous basis.

When one considers other possible methods of continuous fabrication, such as melt pumps, roll or calender methods, etc., he is immediately faced with the fact that a homogeneous melt must be fed to such a device and additional equipment must be available to perform the melting and homogenizing functions. Usually, the conclusion is soon reached that the screw extruder offers the cheapest and most efficient method presently known for accomplishing the necessary functions simultaneously. We can conclude then, that the extruder is here to stay, at least for the foreseeable future.

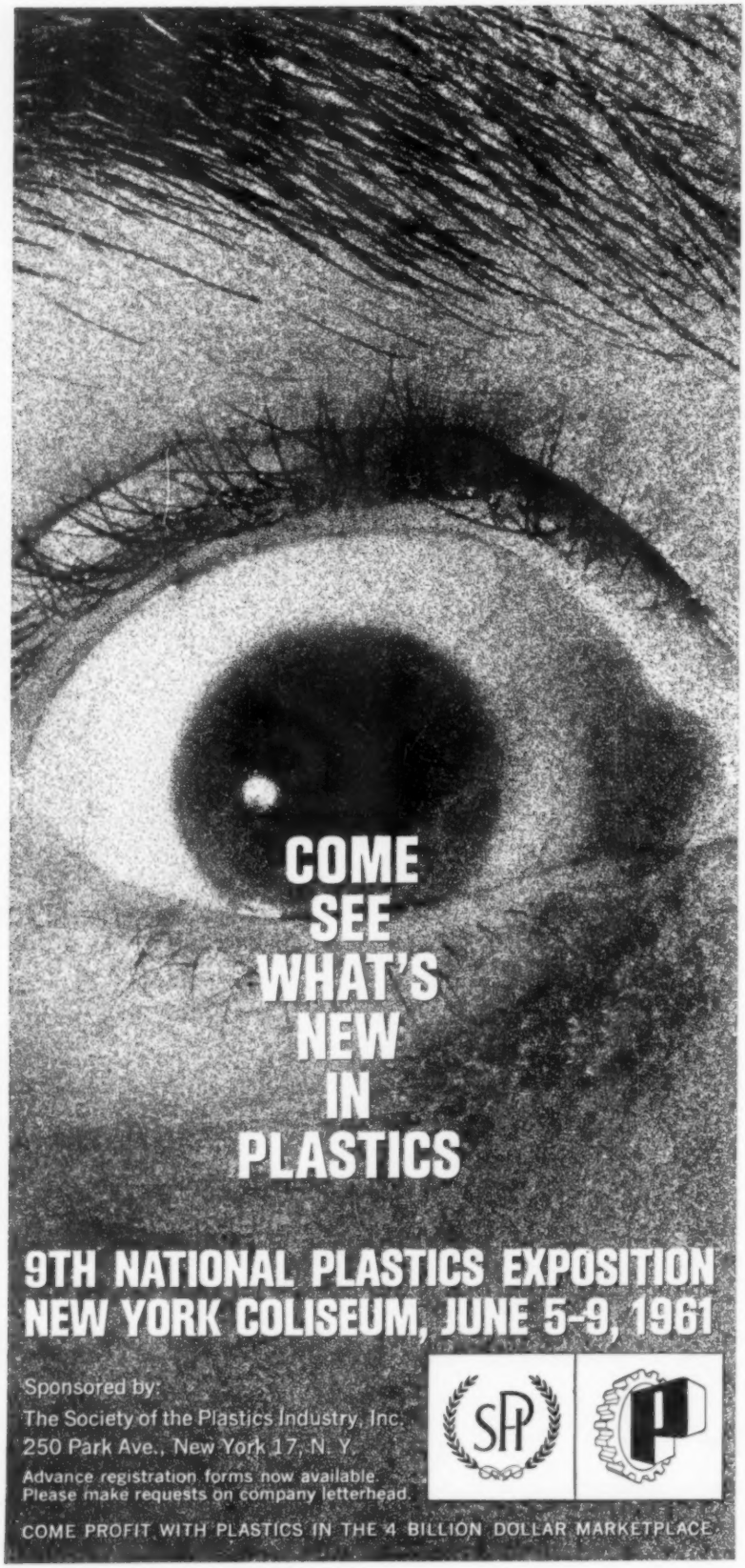
The question then logically arises, where do we go from here? Has the limit of usefulness of the extruder in its present form been reached? If so, can it be modified still further to perform additional functions or operations not heretofore conceived? As plastics engineers, we are inclined to think of the extruder only in connection with the processing of thermoplastic materials. But we all know that extruders have long been used in the food industry—macaroni for example, in soap manufacture, in the manufacture of clay and ceramic products, carbon electrodes, glass, metals and probably many others. As plastics begin to approach metals and other products in mechanical and thermal properties we can undoubtedly take lessons from the experiences of those industries in designing new or modified extruders for more effective handling of such materials.

Three elements of industry—material suppliers, machinery builders, and fabricators—must cooperate to achieve progress in extruder design

The research departments of the raw material suppliers frequently come up with new polymers having mechanical properties which are ideal in many respects but which must remain "on the shelf" because they can not be fabricated with existing types of extrusion equipment. We have all seen rapid expansion of the plastics industry in recent years and an increasing number of new types of plastics appearing each year. There is every reason to believe that this type of growth will continue. It is frequently heard that the burden of responsibility for development of new plastics processing machinery should fall upon the material suppliers because of their advance-knowledge of future needs and greater availability of funds for this type of development activity. While this may be true in some instances, we submit that the basic responsibility should and must be shared by all three elements of the industry—material suppliers, machinery builders and fabricators—and that only by close cooperation of these groups can optimum progress be achieved.

Limitations of Conventional Equipment

Returning to the extruder itself, what are its present limitations and in what areas are improvements needed? We have seen a trend toward the use of higher molecular weight polymers to achieve some advantage in mechanical or use properties—stress crack resistance, for example. Higher molecular weight means a higher melt viscosity and a higher melt viscosity results in increased frictional heat development



in the extruder, increased power consumption and a higher extrudate temperature. This eventually leads to adiabatic operation, over-riding of barrel temperature controllers and further increases in stock temperature with increasing screw speed and output rate. Since many of the applications for such materials—blown bottles, for instance—require low extrudate temperatures for satisfactory fabrication, a problem presents itself—how to achieve suitable quality or degree of mixing at high output rates with a low melt temperature? These requirements appear to be mutually incompatible in extruders of present design, illustrating one limitation of conventional equipment, but does this mean that it is impossible? On the contrary it represents a challenge which, with application of brain power, energy and a reasonable amount of money, is capable of solution.

Here are a Few Directions in which Developments are Visualized Leading to Improved Extrusion Processes

- How do we design an extruder screw, barrel, or both, to better accept wet or lubricated feed stocks? Rifling of barrels is one obvious approach which has been used with some success in specific cases. Is this the best method or the only method of approach? What about multiple screw machines?

- Are presently used methods of venting for removal of air and volatile materials ideal or even adequate? Can anything further be done to eliminate "tricky" operating techniques frequently needed to keep vented extruders in balance?

- Is additional automation of extruders or complete extrusion lines practical? Desirable? Necessary?

- Is high shear necessary for optimum mixing in the extruder? Can comparable mixing and product quality be achieved in multiple screw machines at lower rates of shear and, presumably, lower melt temperatures?

- How much is known about mechanisms taking place in the area of transition from solid to melt? This appears to be the region in which extrusion rate is actually controlled and in which problems of surging originate. What is the optimum design of feed and transition sections of the screw for various materials, including low bulk density powders?

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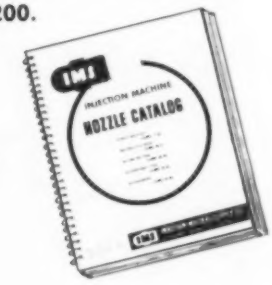

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Richard Maier and Andre Thierstein

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MOLDING CYCLES

Plunger vs Screw Injection Machines— A Comparison

An injection machine has two basic requirements: Plasticizing and Injection. In the authors' opinions, both these functions have close limitations on conventional molding machines and cannot be extended by conventional means.

The Single Stage Plunger Unit—an Analysis

Flow of plasticized material through a conventional cylinder is essentially laminar. There is a distribution of velocity according to *Figure 1*. Even when incorporating flow breaking elements such as fins, strainers etc., turbulence cannot be produced. All these measurements cause the stream of material merely to split-up. The presence of laminar flow becomes obvious when color is changed or when over-heating of a cylinder occurs. Moldings do then bear star-like patterns and the angular pitch corresponds exactly to the pitch of the fins or passages of the spreader.

Variable distribution of velocity in a cylinder leads to non-uniform heating of the polymer. Close to the cylinder wall where the effect of the temperature differential is the most pronounced and where the flow speed could be as little as zero, temperature is the highest, as shown by the group of isothermals in *Figure 2*. The peak temperature of polymer close to the cylinder wall depends upon the temperature differential (T) which for its part is dependent upon the amount of heat that is necessary for plasticizing (Q), thickness of slab of material (δ), heat transfer area (A), time which is at disposal (t), and thermal conductivity (k): $T = \frac{Q \cdot \delta}{t \cdot A \cdot k}$ In order to avoid local overheating at the cylinder wall, the following steps have been undertaken, all of which aim at a decrease of T:

1. keep slab thin by use of spreaders, fins etc.
2. increase heat transfer surface to polymer
3. increase length of cylinder which implies increased time of heat application.

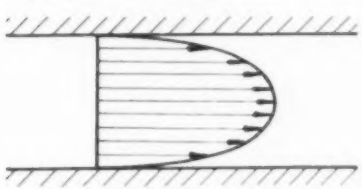


Figure 1. Characterization of flow in cylinder in conventional plunger unit

Editor's Note

One of the most important questions to face American machine manufacturers and molders alike is the question of screw injection machines vs plunger machines. The question is now very much up in the air and will be for sometime. There are arguments for and against. This article is for. And it should be mentioned that there are specific areas of this article where complete disagreement exists with plunger machine manufacturers. It is not the purpose of the SPE JOURNAL *to take sides, but rather to publish articles which have a bearing on the question so that its readers will have a chance to examine for themselves this question of screw vs plunger injection machines. While this article is prejudiced in the "for" direction, we believe that it also contains a very excellent description of the screw injection theory and mechanism, and should help the readers of the SPE* JOURNAL *to make their own comparison of plunger vs screw molding.*

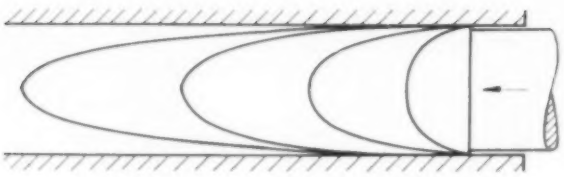


Figure 2. Isothermal showing temperature profile in cylinder, conventional plunger unit. Temperature differential is most pronounced close to cylinder wall—where temperature is highest.

As useful as the first two measures are they have an adverse affect on the flow of resin. Keeping the slab of polymer thin and increasing the contact surface of the cylinder stands in sharp contradistinction to the requirement calling for a hydrodynamically ideal cylinder profile which would embody neither spreader nor fins. The main disadvantage of the hydrodynamically unsuitable cylinder profile is well known and lies in a very poor transmission of pressure. The third measure brings an expansion of time of heat application in favor of a decrease of the temperature differential and is justified for materials with good thermal stability. It is well known, however, that certain products such as rigid PVC can decompose rapidly if it is kept at normal processing temperature for too long a time. Above all, it has to be borne in mind that conditions in a conventional cylinder cannot readily be transferred on to larger units as in view of existing constructional possibilities, the temperature differential is increasing progressively making local overheating inevitable. In addition to this, when large capacity cylinders are used the very differentiated heat distribution shown in *Figure 2* steadily becomes more pronounced, so, that the melt will not attain a homogeneous state.

When criticizing the single stage injection cylinder one can conclude that thermal rheological requirements are in a contradiction which, by means of adequate measurements can be diminished, but not overcome.

The Plunger Type Preplasticizer

The first attempts to improve conditions in an injection unit were carried out in the United States by simply switching two or more cylinders in series according to *Figure 3*. The idea was to give the material more time for the heat transfer and to increase the heat transfer surface whereby at a given throughput of material it was possible to work at a lower differential of temperature. Contrarily, when working on the same temperature differential as on a single stage plunger machine the plasticizing capacity could be increased by a considerable proportion. As the injection cylinder now did not have to fulfill any essential thermal requirements, it became possible to increase the shot volume by a liberal increase of diameter and stroke of the injection unit.

At the same time it is necessary to realize that in the design of preplasticizers it is not possible to avoid flow shadows entirely. Flow shadows are zones of inferior flow speed or zones where the flow speed is not controllable. These flow shadows are produced in dead corners in case of sharp directional changes of the polymer flow or abrupt changes of the flow cross section. The most severe conditions arise in so called dead end cylinders because of the thin layer of plastic sticking on to the front face of the plunger which cannot be forced to move forward in the direction of flow. Such stagnations do inevitably lead to breakdown of the polymer and vary from slight local discolorations to complete decomposition. This circumstance makes the plunger type preplasticizer unsuitable for use with rigid PVC.

All systems involving more than one cylinder or containing externally operated flow control valves must be sealed against molten polymer between injection plunger and cylinder, or between a valve rod and the cylinder. There is a tendency for the polymer to leak across this clearance with leakage at the exterior of the machine. When keeping the clearance at a minimum in order to reduce the leak flow, there is the danger of contaminating the melt because of small amounts of material eventually entering the clearance where they decompose under frictional heat, and from where they are carried into the injection chamber.

The Screw Type Preplasticizer

It is well known that the melt delivered from an extruder was much superior to the melt of an injection molding machine with regard to homogeneity. The explanations of this phenomena follow.

A substantial part of heat which is necessary for melting is generated in the polymer itself by conversion of mechanical energy. The balance of heat is put into the material by convection whereby the polymer is in continuous turbulence so that a very small temperature differential can be applied. In addition to this, the path of melt up to the nozzle is very clear and direct, without flow shadow causing elements. Cylinder walls are continuously swept clean by the flights of the screw.

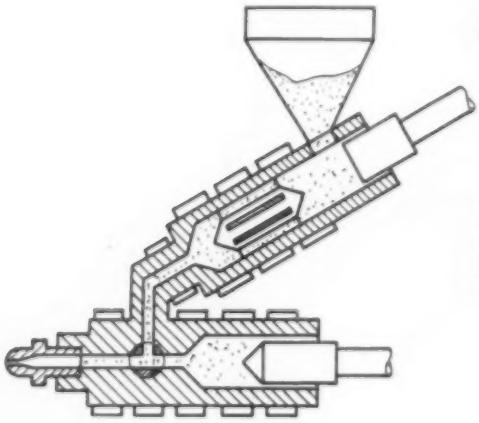
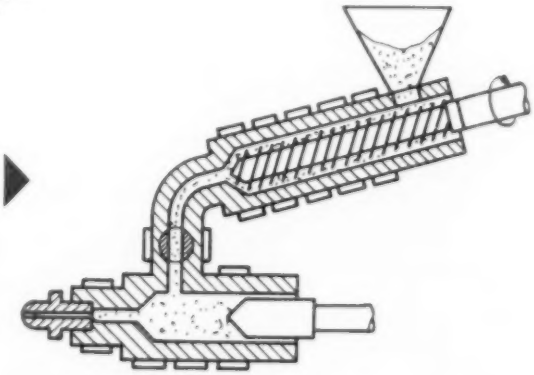


Figure 3. Plunger type preplasticizer

Figure 4. Screw type preplasticizer



Thus it was possible to feed an injection cylinder with molten material of high quality delivered from an extruder. As a result of this combination quite a variety of solutions has appeared on the market in the last few years (*Figure 4*).

All these combinations unite the features of plunger preplasticizing with the good quality of melt from the extruder. Among the disadvantages of plunger preplasticizing, however, the ones concerning flow shadow and leak flow are very distinct and imply that the screw preplasticizer too is excluded from working with heat sensitive materials, such as rigid PVC. With these units it was still possible, however, to increase the melting capacity as well as shot volume of the plunger type preplasticizers.

The Reciprocating Screw Type Injection Unit

The next step in the development of injection units was based on screw plasticizing. In a 1939 French patent the idea of the reciprocating screw appeared for the first time. *Figure 5* shows how it was presented. This unit, however, was supposed to work with rubber instead of thermoplastics. Patents to cover the application for thermoplastic materials were granted in 1952 to BASF, Germany and in 1956 to F. W. Egan Company, United States.

The typical cycle of this kind of injection molding machine follows.

1. Close mold
2. Injection by forward stroke of the non-rotating screw under hydraulic pressure. Unload pressure as desired.
3. Rotating screw. Screw is pushed backwards under the pressure of material which is delivered to the cylinder head by the screw itself. After a predeterminated position is reached, a limit switch is tripped which causes rotation to stop. In this position there is as much material accumulated in front of the screw as will be required for the proceeding shot.
4. Open mold, eject molded part.

This description of the cycle shows that the bringing back of the screw has to be accomplished within the cooling time of the molding but, on the other hand, should be kept on as long as the cooling time permits. Thus, in order to give the screw an optimum speed, stepless speed control is provided in most of the existing molding machines of this type. Another element governing the revolving time of the screw is the height of back pressure which the screw has to overcome on its way back.

The chief task of back pressure, however, is governing the shear which is imposed on the polymer on its way along the screw. With the control of back pressure it is possible to predetermine the amount of heat generated in the polymer itself by direct conversion of mechanical energy. This is in contradistinction to a normal extruder where control of shear is not that easy.

Additional heat input by electric heater bands is desirable for starting from cold and for additional controllability. Temperature differentials may be kept very low because of the phenomena that the apparent heat conductivity of a polymer, while being mixed by transverse flow, can be as much as one hundred times higher than the one with laminar flow in a conventional cylinder. Thus, melting is done in a very smooth way although the output is considerably higher than on a plunger machine of comparable size.

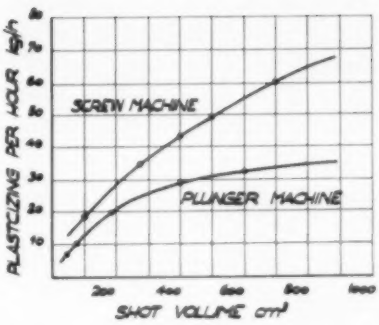


Figure 6. Melting capacity of plunger and screw machines plotted against shot volume

Graph *Figure 6* shows melting capacity of plunger and screw machines plotted against shot volume. Whereas the curve for the screw machine goes up almost proportionally to the shot volume, the curve for plunger machines asymptotically approaches a maximum. The favorable heating efficiency is also demonstrated by the low value of electric heating capacity installed in the machine.

Because it is possible to control the amount of shear put into the screw it demonstrated that the same screw was suitable for processing rigid PVC in form of granules as well as in form of a dry blend. This, in spite of the fact that the length of screw compared with the one in an extruder was extremely short. This playing with back pressure has also been used for dry coloring: Increased transverse flow disperses pigments and master batches with great uniformity all over the mass.

The capacity of a screw cylinder is not higher than a double shot volume. Accordingly the dwell time of the polymer in the cylinder is extremely short in contrast to a conventional cylinder which usually contains more than 10 shot volumes. This is an advantage when changing color.

When judging the performance of injection of a single screw machine, one could assume at the first approach that the plastic accumulated in front of the screw would, under the high compression of injection, tend to flow backwards along the screw channels. This would correspond to the well known pressure flow Qp existing in extruders. This consideration does arise before all when long holding times of injection pressure have to be maintained. Practical operation has shown, however, that, if the individual heating zones are set at the right temperature and if water cooling at the beginning of the feed zone is provided so that a tightly compressed plug is formed, there would be no problem

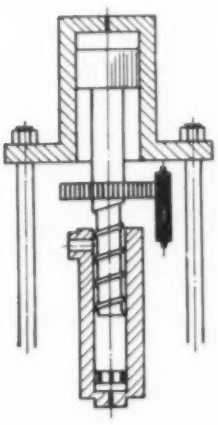


Figure 5. Reciprocating screw patented in France in 1939, was for working with rubber

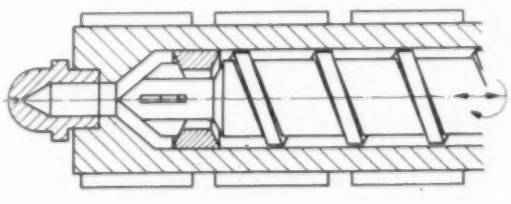


Figure 7. Schematic showing non-return valve at tip of screw

TENITE DEVELOPMENT LABORATORY DOINGS AND FINDINGS

WITH A LITTLE BIT OF LUCK

Remember the story of the Chinese boy who "discovered" roast pork the day his house caught fire and his pet pig failed to escape? A legend, probably — but logical. Chance has undoubtedly played a major role in many a discovery. Five or six years ago, for instance, some plastics engineers were watching experimental polyethylene paper-coating trials at a plant in upstate New York. Their eyes widened when the paper accidentally broke and the polyethylene coating continued to emerge from the chill-rolls . . . as highly lustrous film! Like the Chinese lad, the engineers got the implication. Today, chill-roll extrusion is a well-established technique for fabricating sparkling, highly transparent polyethylene film.

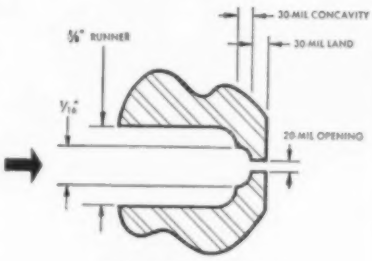
By investing in high-speed, chill-roll equipment for its own test purposes, Eastman has been able to develop excellent film-grade Tenite Polyethylene formulations for specific end uses such as bread overwrap.

SMALL GATE—BIG HELP

Every molder loves a small gate; it makes possible a part that comes quickly free of the mold and requires no trimming. Unfortunately, it may also impede flow, thus preventing the cavity from filling completely or slowing the molding cycle.

Through their test work with Tenite Acetate, Butyrate, and Propionate, Eastman's engineers have hit upon a new design for a 20- to 30-mil gate that often works where the conventional pinhole gate fails. Even where the pinhole gate has been found satisfactory, indications are that the new design can speed the molding cycle.

Here is the new design:



MODIFIED PINHOLE GATE

It differs from the conventional pinhole gate in just one small, but very important, way. The runner (or sprue, if runners are not used) stops just short of the gate's land. A machined cavity half the size of the runner then extends it to the land.

What makes the design work so well, we think, is the flow pattern that develops as the hot plastic enters the gate. The wave-front traveling down the runner breaks across the small concavity and forms streamlines that help the plastic shoot smoothly through the gate and into the mold.

A COOL 6 BILLION

Six billion pounds of frozen food, we're talking about. That's the astronomical figure projected for 1970. Naturally, the packaging for such a harvest takes on prime importance. Eastman's popular entry in this pouch-packaging field: Tenite Polyethylene 161M Natural. This new polyethylene formulation, with a density of 0.923 and a melt index of 0.7, has been exceptionally well-received for making film used to package foods that are IQF—individually quick frozen. The significant word is individually. With each little pea, bean, or carrot cube frozen separately from its fellows, vegetables remain loose rather than becoming a solid block, and can be poured from the package in just the quantity needed for immediate use.

A preliminary survey (we asked our wives) reveals that the housewife not only prefers IQF foods because of their loose form, but also finds the polyethylene pouch much easier to open than boxes.

For more information on Tenite Polyethylene 161M, contact your nearest Tenite representative or write to Eastman Chemical Products, Inc., Plastics Division, Kingsport, Tennessee.

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in holding injection pressures far beyond practical requirements for any length of time.

It must be admitted however, that setting the controls of a reciprocating screw machine needs more care and skill than is the case on a conventional machine. This applies mainly to how to prevent pressure flow as intimated above. For this reason it has become practice for materials having a very low melt viscosity such as Nylon, to fit the tip of the screw with a simple non-return valve as shown on *Figure 7*. This valve leaves the passage free when the screw rotates and material is delivered to the front of the screw. On injection the ring valve mates the screw shoulder and automatically separates the screw channels from the pressurized material in the cylinder head. Remember that the non-return valve should always be considered as an auxiliary measure which should not become a rule as it impairs the cleanliness of the flow of material through the cylinder. It would not be permitted for use with rigid PVC. Leak flow to the external of the cylinder, as it has been discussed in connection with preplasticizers, does not exist with this system. Sealing against leakage of molten material is achieved by the cold plug of material itself, in the same way as is done in conventional plunger machines.

On the forward motion of material no major frictional resistance has to be overcome. This means that the pressure which is produced by the ram is not dissipated by the resistance of spreader, fins etc. and consequently does not need to be considerably higher than the pressure required for filling the cavity. It has been found that materials with high melt viscosities such as rigid PVC, Polycarbonate, and Polyethylene with a melt index 0.3, where suppliers recommended the injection pressures to be as high as 30,000-40,000, could be processed on the screw machine with no difficulties at all at pressures not higher than 14,000.

As a result of the most favorable frictional conditions in the cylinder of a screw machine much higher injection speed can be obtained than on plunger machines, provided that the hydraulic plant is supplying oil at an adequate rate, an advantage in high rate of injection molding thin-walled pieces.

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Edited by
Milton A. Sanders,
Precision Molding Incorporated

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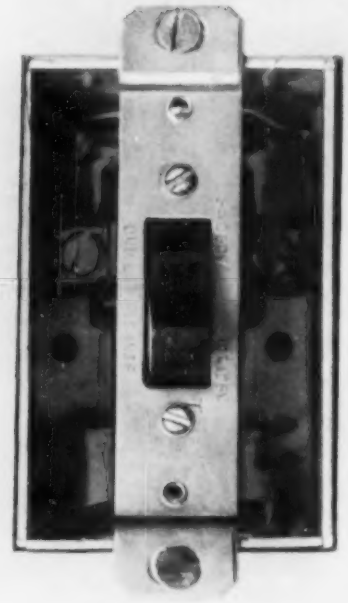

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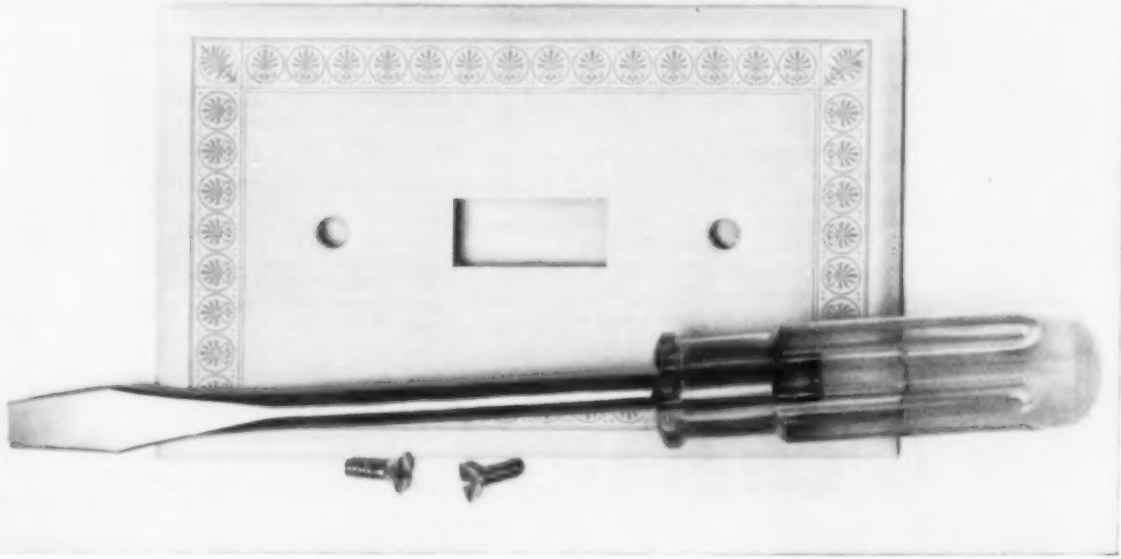

Each of these extrusions of rigid Geon by Crane Plastics, Inc., Columbus, Ohio, is in use for various architectural applications—chiefly windows. B.F.Goodrich Chemical Company supplies the rigid Geon vinyl.

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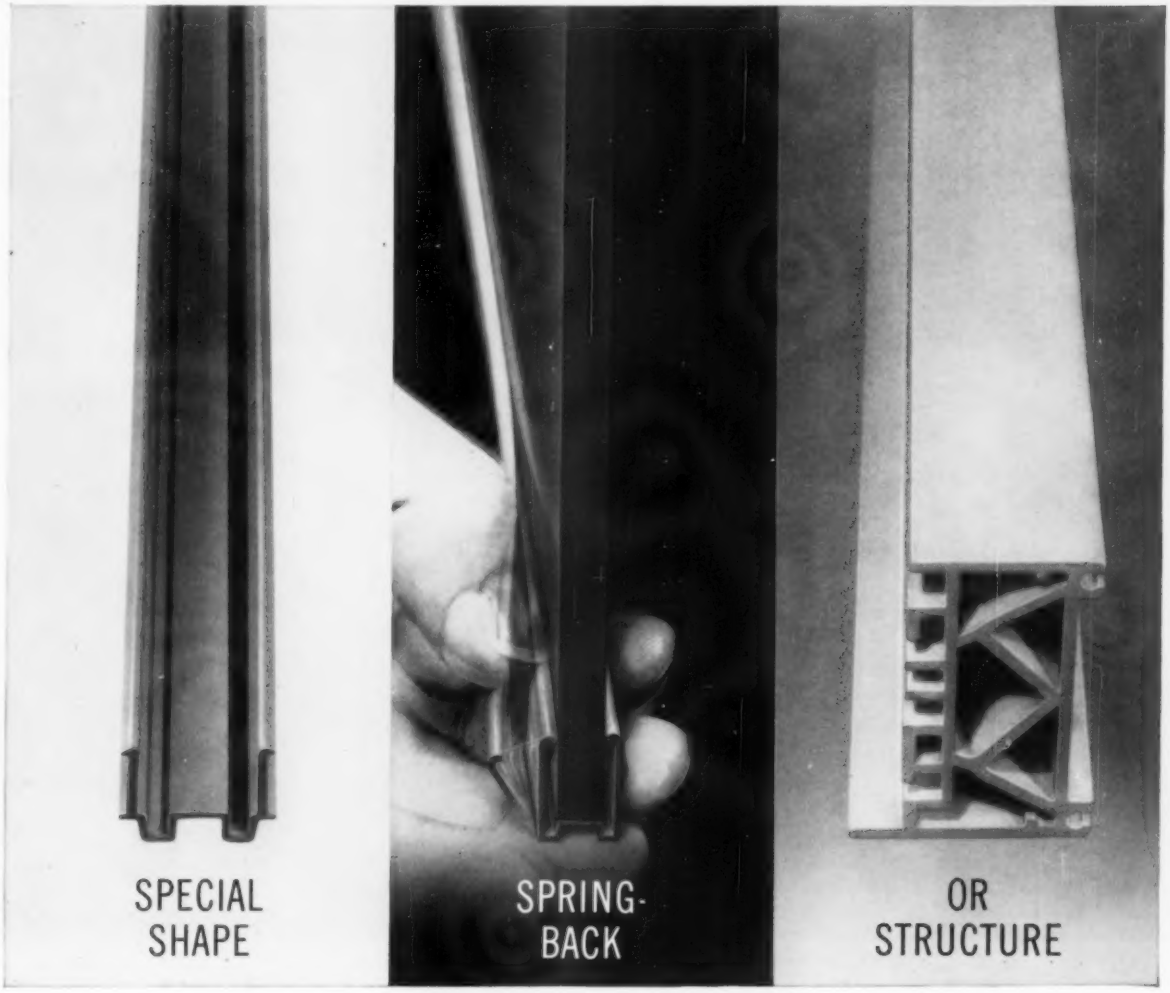

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best of ANTEC -1961

The following technical section contains articles selected by the Society's Editorial Advisory Board and Editors and designated to be the Best of ANTEC. While, in past years, the philosophy behind the idea of having a Best of ANTEC issue has been adequately stated, it should be stated again. It is presumptuous to designate certain papers as being "best." However, by setting some standard of technical quality, incentive is provided for the presentation of papers of high value in the field and in the profession at future Conferences of the Society.

Since the Society is now publishing SPE TRANSACTIONS, the method of selection and subsequent publication was different than in years past. Because the editorial scope of a paper is more suitable for publication in SPE TRANSACTIONS rather than the SPE Journal is no valid reason for excluding that paper from Best of ANTEC consideration. Therefore, selections were based on value first, with the editorial scope of the paper determining whether it will be published in TRANSACTIONS or the Journal. As it developed, there were a total of 10 papers selected Best of ANTEC out of a field of 102, with six published in this issue and four to be published in the July 1961 issue of SPE TRANSACTIONS.

A preview of several articles for the third quarterly issue (July) of SPE TRANSACTIONS are found below.

Thermodynamic Diagrams for Polyethylene Resins

J. M. Lupton, *Polychemicals Department, E. I. du Pont de Nemours & Co., Inc., Wilmington, Delaware*

Diagrams showing the effects of pressure, volume, and temperature on thermodynamic properties such as enthalpy, internal energy, and entropy are well known for simple substances and serve many purposes in science and engineering. Such diagrams for thermoplastic resins have been less frequently used, reflecting many complications in acquiring and interpreting the necessary data. However, recent studies show that a series of assumptions can be used to develop useful new diagrams of wide scope for polyethylene resins.

The Strength of Glassy Polymers

J. P. Berry, *General Electric Co., Schenectady, New York*

The Griffith theory for brittle fracture predicts that the tensile strength should be inversely proportional to the square root of the size of a defect or flaw in the sample tested. The validity of this relation has been investigated for the glassy polymers, poly (methyl methacrylate) and polystyrene. The results indicate that the strength of the polymers depends on two factors: (1) the surface energy, and (2) the inherent flaw size. The surface energy is primarily that dissipated in a viscous flow process and the inherent flaw size is related to the tendency of the polymer to craze under stress.

The Effect of Extrusion Variables on the Fundamental Properties of Tubular Polythene Film

N. D. Huck and P. L. Clegg, *Imperial Chemical Industries, Ltd., Welwyn Garden City, Herts, England*

The mechanism of formation of tubular polythene film is a complicated process, and extensive studies have shown that the properties of the film made are influenced profoundly and in a complex way both by the processing conditions used and by certain design features of the equipment. Studies of the effect of the extrusion variables on the more important film properties, both optical and mechanical, are reviewed in this paper. The results are discussed in terms of the fundamental nature of polythene film, its surface, its crystalline structure and its orientation. It is shown that the properties are determined almost completely by the melt history from just before the die to just after the freeze line. Die profile, melt drawing and cooling are therefore of prime importance in the control of the appearance and strength of the film produced.

Flow Patterns in a Non-Newtonian Fluid in a Single-Screw Extruder

W. D. Mohr, J. B. Clapp, and F. C. Starr, *Polychemicals Department, E. I. du Pont de Nemours & Co., Inc., Wilmington, Delaware*

Flow patterns in the channel of a screw extruder have been investigated in a study utilizing a model extruder with stationary screw and a rotating, transparent barrel. Photographs of flow streamlines at conditions over the full range of output restrictions are presented for a non-Newtonian fluid. A technique employing photographs of particle tracers was used with the same apparatus to permit quantitative measurement of velocity profiles with both a Newtonian and a non-Newtonian fluid.

Every Month—the *significant* NEWS OF PLASTICS ENGINEERING **SPE JOURNAL**

The Rotating Spreader— A Device For Superior Injection Molding

Neil Keiser *was born in Paterson, New Jersey. He graduated from Newark Technical School receiving an A.E. in Chemical Engineering. He attended Newark College of Engineering and Rutgers University. In May 1937 he joined the du Pont Plastics Department at Arlington, New Jersey. Except for four years of duty with the Air Force as pilot and staff officer during World War II he has been associated with plastics research and development for the past 23 years and is now assigned to the Polychemicals Research and Development Division at Wilmington, Delaware. Mr. Keiser is a member of the Philadelphia Section of SPE and serves on the National Executive Committee of the Injection Molding PAG.*

L. Hart Cirker *was born in Brooklyn, New York. He attended the Massachusetts Institute of Technology where he received a B. S. in Chemical Engineering in 1933 and an M. S. in Chemical Engineering Practice in 1934. He later continued his studies at the Polytechnic Institute of Brooklyn. He joined the du Pont Company at Arlington, New Jersey in 1935 where he worked on research development and production problems on Plastics. He is at present supervisor of Engineering Services of the Polychemicals Department, Research and Development Division, Wilmington, Delaware. His professional memberships include SPE and AIChE.*

Paul D. Kohl *was born in Terre Haute, Indiana. He attended Purdue University receiving a B.S. in Mechanical Engineering in 1946. He joined the du Pont Company in September of that year and was assigned to the Belle Works, Charleston, West Virginia. In February 1948 he was transferred to the Experimental Station in Wilmington. He is presently serving as a project leader—design and mechanical developments for the du Pont Polychemicals Department. Mr. Kohl is an active member of ASME.*

Use of injection molding machines equipped with rotating spreader improves molding quality, volume of production and color mixing. Inexpensive conversion of a 6-ounce machine and resulting benefits are described

Neil Keiser, L. H. Cirker, P. D. Kohl
E. I. du Pont de Nemours & Co., Inc.
Polychemicals Department

The conventional single-cylinder injection molding machine as used today is a highly refined, versatile mechanism capable of producing on automatic cycles, molded parts of accurate dimensions. However, as evidenced by the literature and by numerous papers presented at SPE meetings, the present machines have deficiencies. (1, 2, 3, 6) Some of these are:

(a) Limited ability to produce a plastic melt of uniform temperature; this results in highly stressed molded parts or in degradation of thermally sensitive plastics.
(b) Limited mixing ability thus requiring special care when blending colors.

Therefore, a superior method for upgrading injection molding machine performance was sought. Beyer, Dahl, and McKee (1) had shown in 1955 that flow of plastic melts through the injection cylinder is laminar in nature, i.e., there is little if any mixing between layers of the plastic flowing through the cylinder; because of this laminar flow, problems arise of temperature and composition non-uniformity. It is apparent that positive mixing of the plastic melt is needed to overcome these deficiences.

We tried to achieve this mixing by making relatively simple modifications to an existing conventional injection molding machine. Power was applied to rotate the spreader or torpedo while molding. This rotating spreader arrangement is shown in *Figure 1*.

In this arrangement a straight bored cylinder of 2-3/16-in. diameter fitted with a rotating spreader much shorter than

BEST OF ANTEC!

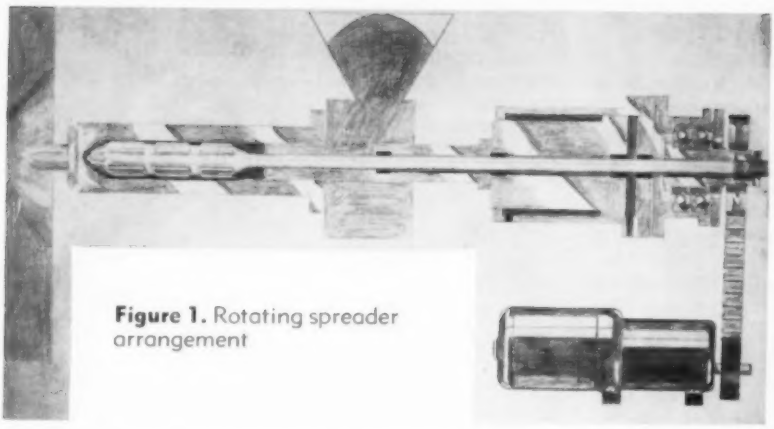


Figure 1. Rotating spreader arrangement

the conventional spreader was used. It is attached to a 1-in. diameter shaft which extends back through the injection plunger and the hydraulic ram and is attached there to the drive mechanism. Where the shaft passes through the ram and plunger either a snug fitted bushing or oil seals in the appropriate locations can be employed. The drive shaft is supported at the rear of the hydraulic injection cylinder by a thrust bearing assembly. The spreader floats in the melt zone supported only by the drive shaft. The size of the drive mechanism will vary with the size of the machine on which the rotating spreader is installed, but in any case it can be small with limited power capacity. It can be either a fixed or a variable speed drive depending upon the use to which it is put. After experience has been gained with a variable speed rotating spreader for a particular material or on a particular job, a fixed speed drive will generally be adequate.

In this arrangement we have a versatile tool. The positive feed action that one obtains with a piston plunger feed mechanism is maintained. In addition, there is a rotating mechanism for mixing and plastifying which has independent speed control which can be varied as desired. *Figure 2* shows two of the several designs of the rotating spreaders that have been evaluated. These models work about equally well and have been tested with a wide variety of materials over a range of conditions.

Although originally the intent was primarily to modify the injection machine to obtain melt of better uniformity, experiments with the rotating spreader disclosed a number of additional or concurrent advantages. The improvements found are tabulated as follows:

- A more uniform melt temperature
- Lower molding pressures
- More molded parts per hour with better dimensional stability
- Improved dry color blending in the machine
- A rapid changeover from one material to another
- Homogeneous blending of scrap and reground material

The Advantages—Discussion

More Uniform Melt Temperature. Beyer, Dahl and McKee in their work on the evaluation of the injection heating cylinder showed that temperature variations within the single shot from a standard cylinder are as much as 47°F. Using various standard machines as a control for the rotating spreader evaluation, their values were very closely checked and temperature variations found to be from 36 to 54° on various machines with standard cylinders. By installing the rotating spreader and using the same equipment it has been possible to reduce the temperature variation within a given shot to only 7 to 10°F. This is a major improvement in the uniformity of melt temperature, and hence results in better quality moldings. A rotating spreader offers additional advantages as far as melt temperature is concerned when working with a heat sensitive polymer. It is possible to reduce the external temperature of the cylinder when using a rotating spreader, because rotation is both providing mechanical heat and is continuously wiping the cylinder wall thus increasing the overall heat input rate. Cylinder temperature settings can be reduced as much as 40°F for a given molding job, it is found. On the other hand, to achieve high production, higher wattage heaters can be used at rapid injection rates because hot spots are eliminated. The melt extruding from the nozzle will have a temperature variation as indicated, even with the high wattage heaters, of only 7 to 10°F.

Figure 3 shows a typical temperature measurement made using a thermistor probe and a Sanborn recorder to show the variation. The comparison of a standard spreader versus the rotating spreader can be seen.

Figure 3 compares the temperature variation measured at the exit of the nozzle from a single shot. Three shots are shown in sequence as can be seen from the continuity of the curves made on this Sanborn recording. Note that only a 7° spread was measured in the shot made using the rotating spreader as compared to 37° using the standard spreader.

Lower Molding Pressures. For this experimental work, in order to measure pressure drop across the plastifying cylinder, a pressure transducer was used on the hydraulic

Figure 2. Photograph shows several designs of rotating spreaders

Table 1. Comparison of Pressure Drop Through Cylinder

STATIONARY SPREADER

Resin	Pressure Hyd. Cyl.	Pressure Nozzle	Pressure Drop ΔP	Pressure Drop %
Methyl Methacrylate	19,500 psi	4,100 psi	15,400	79.0
Polyethylene	16,800 psi	8,000 psi	8,800	52.4
Acetal	20,000 psi	9,100 psi	10,900	54.5
Nylon	19,100 psi	8,500 psi	10,600	55.5

ROTATING SPREADER

Resin	Pressure Hyd. Cyl.	Pressure Nozzle	Pressure Drop ΔP	Pressure Drop %
Methyl Methacrylate	7,200 psi	6,400 psi	800	11.0
Polyethylene	7,020 psi	6,000 psi	1,020	14.5
Acetal	11,700 psi	9,000 psi	2,700	23.1
Nylon	11,700 psi	9,600 psi	2,100	17.9

injection cylinder and a pressure gage in the nozzle. The nozzle gage was a strain gage type developed by Paul Kohl and is similar to the one described by Kohl at the 1957 17th Annual Technical Conference (7).

With the use of these two pressure measuring devices and a Sanborn recorder, the pressure drop across the cylinder can be measured and recorded. Normally, with conventional equipment, these measurements showed a pressure drop from 50 to 80% across the cylinder. By installing a rotating spreader, for most moldings it is possible to keep pressure losses down to 10 to 20% and never exceeding 50%. This, of course, has a number of advantages. It permits molding at lower pressures and hence reduces the amount of strain induced in the molded pieces. It gives an opportunity to enlarge the size of the projected area to be molded. It gives more rapid rates of injection with shorter fill times.

Because of this decreased resistance to flow through the cylinder, as shown in *Figure 4*, the mold fill time is reduced. In this particular instance, a savings of 4 seconds was recorded in the fill time; hence the normal molding cycle could be shortened by this amount. This particular recording was made with Du Pont's Alathon® polyethylene resin.

More Molded Parts Per Hour With Better Dimensional Stability. The next advantage found was a higher production rate coupled with better dimensional stability. Since hot spots are virtually eliminated, heater bands can be operated

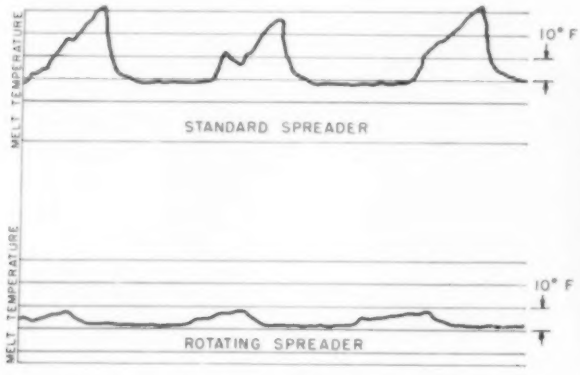
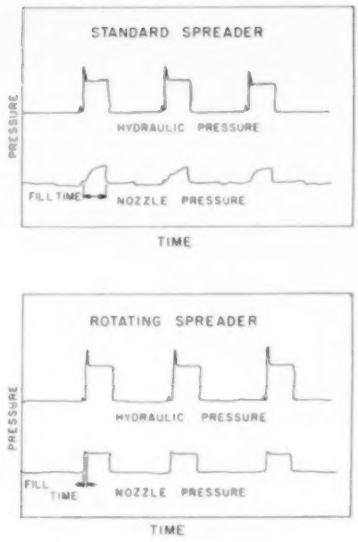


Figure 3. Stock temperature at nozzle

Figure 4. Molding filling time—rotating spreader compared with standard spreader



at higher temperatures. Heat transfer is improved. This plus the heat generated by mechanical working of the polymer produces melt more rapidly and gives a greater melt capacity. Hence, the polymer can be moved through the cylinder at a more rapid rate. This is coupled with lower resistance to flow. It is quite obvious then that a higher production rate can be achieved without sacrificing the quality of the part. *Figure 5* shows the improvement in quality maintained even at high production rates. The tumblers seen were molded from an acrylic resin. They were both immersed in a water bath at 85°C for 15 minutes. Note the clarity and smoothness of the tumbler on the right which was made using the rotating spreader. It is still possible to read through it. Also note the dimensional change in the tumbler on the left made with the standard spreader.

Color Dispersion. The next advantage is the improved color blending in the machine. Up to now, many devices, such as dispersion nozzles, have been proposed to give improvements in the dispersion of color. (4, 5) Unfortunately, with the devices tested additional pressure losses were incurred and only marginal improvements in color dispersion were obtained. The high pressure loss necessitates the use of still higher injection pressures, and this can result in highly stressed pieces, which of course, would be objectionable. With the rotating spreader, no additional mixing devices are needed. A color feed produced by simple tumbling of resin and dry pigment in a container for a few minutes is all that is required. The rotating spreader accomplishes the rest of the color dispersing.

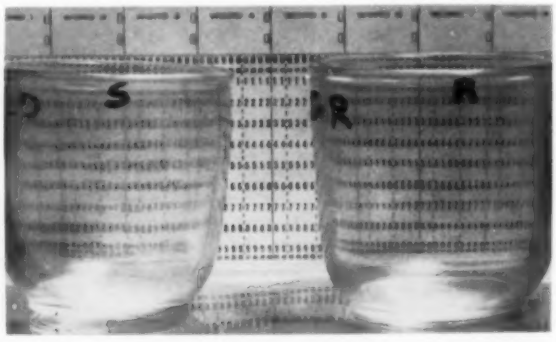


Figure 5. Photograph shows improvement in quality at high production rate

Table 2. Purge Quantities Required on Change Over 6 Oz. Machine

Resin	Color	Amount to Purge
Polyethylene	Natural	—
to	Black	1 pound
to	Natural	2
to		
Methyl		
Methacrylate	Crystal	2
to	Blue (dry pigmented)	¾
to	Crystal	2
to		
Acetal Resin	Natural	2
to	Blue (dry pigmented)	¾
to	Natural	2
to		
Methyl		
Methacrylate	Crystal	2

Many combinations of pigments and resins were tested with this device and in all cases, excellent dispersion was accomplished. This also leads to the next advantage found, the ease of purging the machine to change colors.

Color Change and Purge. *Figure 6* shows the change over from yellow to natural in tumblers molded from nylon resin (actual color change can't be shown in black and white; however the change is indicated by the different degrees of shading). This series of shots required a total of two pounds of resin. Below this is a purge series from blue pigmented polyethylene to crystal acrylic. This demanding color and material change required only five pounds of resin. The samples demonstrated were made on a 6-oz. machine. Of course, as one increases the size of the machine or the cylinder in the machine, there is more area to be swept clean and more polymer to remove. However, with larger cylinders, even a complete color changeover can be made with a few pounds of material. *Table 2* shows a chart giving actual pounds for purged material required on our 6-oz. machine.

Blending of Scrap and Reground Material. The next advantage found is the superior blending of scrap and reground material. Normally, most molders will take their sprues and runners that have been reground and feed them back into the machine while blending for a minimum time with a minimum amount of virgin material. Since little mixing takes place in standard injection cylinders, the quality of molding made using this blend of material is naturally poorer because of the non-homogeneity. Also, molecular

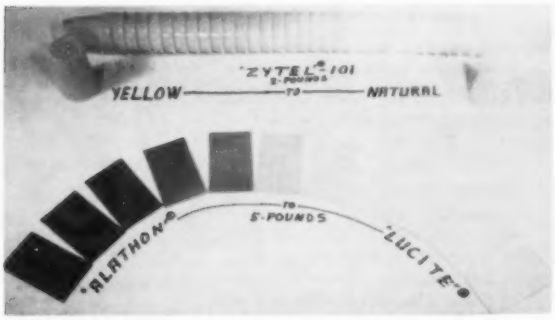


Figure 6. Complete color changeover can be made with a few pounds of material

weight decreases or changes in melt index that might occur on the second time through the machine will affect the quality of molded parts. With a rotating spreader a homogeneous blend will be extruded into the mold. As seen in *Figure 6* there can be very little question as to the homogeneity of the blending of rework or scrap with virgin polymer.

Experience

A few things should be mentioned about actual experience with this device. Rotating spreaders on machines ranging from one ounce up to eight ounces in size were used. One 8-ounce machine in a production molding plant has been running continuously around-the-clock, 7 days a week, for well over one year with almost no maintenance problems and is still going strong. This is no doubt a good indication of the mechanical reliability of this particular arrangement. A 6-ounce machine used for most of this experimental work in the laboratory has been in operation intermittently for a period well over two years and has been disassembled and put together over a hundred times, indicating again a very successful experience. Despite the frequent tearing down and setting up and operating with a wide variety of plastics, no major difficulties were ever encountered.

Design and Construction

Proper consideration must be given to the design and to the selection of materials of construction in order to make a rotating spreader installation a dependable and useful device. The spreader should be made of a material of adequate strength to withstand the drive torque, in the area where it is threaded to the shaft. The spreader should be relatively short in order to provide space for preheating between the plunger forward position and the rear of the spreader. This arrangement reduces both pressure drop and stresses on the spreader drive. The overall spreader length is suggested at roughly 2/3 the distance from the face of the plunger in its forward position to the rear face of the cylinder nozzle. The spreader should be of streamlined design to reduce possibilities of hold-up. Straight blades oriented parallel to the spreader axis work well and are easy to machine. The blades should be widely spaced and arranged to sweep the cylinder wall. Clearances between the spreader and cylinder are not critical; 1/32-inch. was used. Adequate clearance should be made at the nose of the spreader to allow for the elastic elongation of the drive shaft under the forward thrust load.

The drive shaft reduces the single shot capacity but since adequate hydraulic pressure is available this can be compensated for by enlarging the cylinder. The drive shaft should be of a high strength steel to provide adequate strength for the torsional and pressure load while occupying a minimum space within the cylinder. "Elastuf 44", a machinable, high strength, chrome nickel molybdenum steel of Rockwell hardness 42 to 46 which has an ultimate tensile strength of 180,000 to 200,000 psi, and a shear strength of 100,000 psi was used. The thrust forces, both forward and reverse which are considerable in this design, are estimated by calculating the total thrust on the area exposed to the push of the piston i.e., the thrust exerted by the hydraulic plunger and assuming the same thrust on the reverse area exposed to the back pressure from the mold. Thrust bearings were chosen on the basis that they will withstand 50% of these calculated thrusts at the rotational speed. Because the peak thrust loads are only momentary, this provides an adequate design safety factor.

The oil seals used on the shaft were standard O rings with leather backup rings on each side. It is recommended that polymer fines be kept out of the forward seal by use of a wiper ring and a vent at the back of the injection ram.

The drive for the spreader can be, as previously noted, of moderate size. In a (6 oz.-2-3/16" Dia.) installation, only a one horsepower drive geared was used to rotate the spreader at speeds from 25 to 75 rpm. This proved to be underpowered for operating with the more viscous plastics. It was replaced with a 3 HP drive with a top output of 25 rpm. This drive has ample power to rotate a 2⅞-inch diameter spreader under maximum injection pressures with the most viscous plastics. For example, it was possible to operate with extremely high melt viscosity grades of Delrin® acetal resin, Zytel® nylon resin, and Lucite® acrylic resin designed for *extrusion* and not for ordinary injection molding.

Low rotational speeds provide both adequate mixing and sufficiently good heat transfer. Thus any benefits with the 2⅞-inch spreader from operating above 25 rpm have not been observed. It is likely that scale up can be made to larger spreaders by maintaining the same peripheral speed and by increasing the horsepower in proportion to the peripheral area of the spreader.

Improper operation, such as starting up when unmelted resin surrounds the spreader, can result in damage to the assembly. Therefore, some protection against excessive torque is recommended. The simplest device is a shear pin in the high torque end of the drive train. More satisfactory and still inexpensive is a torque limiter. This can be used to drive the chain sprocket at the output of the gear reducer.

Cost

What is the cost of such an installation? The first large machine converted was a 6-ounce horizontal machine which already had a straight bored cylinder. For this changeover the rotating spreader itself had to be built to provide the ground drive shaft, bore the plunger and the hydraulic ram, provide the bearing and necessary seals, and buy and install the drive mechanism. This complete changeover of the 6-ounce machine cost less than $2,000.

This cost is probably average for a simple conversion on a machine already equipped with a cylinder suitable for the installation of a rotating spreader. Where a new cylinder and plunger must be purchased the cost will be about $4,000 or higher depending on the type of drive selected and modifications to the hydraulic system. However, because of the low resistance to flow and low pressure drop of the rotating spreader, an oversized cylinder and plunger can be used to obtain simultaneously a considerable increase in both shot size and plastifying capacity.

Installation of a rotating spreader is undoubtedly a superior method for up-grading injection molding machines and will provide a tool which will help produce better quality moldings at much lower costs.

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Effects of Basic Polymer Properties on Injection Molding Behavior

How injection molding is affected by:

- *Heating rate of polymers*
- *Polymer flow properties*
- *Uniformity of mold temperature*
- *Polymer shear rate*
- *Orientation of molecules*

R. B. Staub, *Union Carbide Plastics Co.*

Injection molding is still both science and art. The continually needed reduction of art to science always requires the identification and control of certain fundamental variables. The injection molding behavior of polymers is determined by their thermal properties and flow properties. Thermal properties include specific heat, thermal conductivity, thermal diffusivity, crystallinity at normal temperatures, transition temperature, and change in volume with temperature. Flow properties include Newtonian or non-Newtonian behavior during flow, and viscosity, which is related to the polymer structure.

Data on a variety of polymers will be presented, showing the dependence of injection molding behavior upon these thermal and flow properties. Data from the laboratory and related literature serve to bear out this dependence.

Roger B. Staub *was born in Lock Haven, Pennsylvania, in 1935. He received his B.S. degree in Chemical Engineering from the Pennsylvania State University in 1956, and immediately joined the technical staff of the Union Carbide Plastics Co. Development Laboratories in Bound Brook, New Jersey. His work at Union Carbide involves injection molding process and product development with polyethylene and polystyrene materials. His paper on molding polyethylene presented at the 1960 ANTEC was among the papers selected "Best of ANTEC." He is a member of SPE, and is currently serving his second term as Chairman of the Injection Molding Professional Activity Group.*

Thermal Properties

The relative ability of a material to change temperature is called *thermal diffusivity*. Basically, it combines the quantity of heat required to raise the temperature (specific heat) with the rate at which the material can accept heat (thermal conductivity). Thermal diffusivity is expressed as:

$$\text{Thermal Diffusivity, } = \frac{K}{C\rho}$$

where K = thermal conductivity
C = specific heat
ρ = density

Heat energy is required not only to raise the temperature of a polymer but also to accomplish change of state in certain polymer types. Comparisons of the injection molding behavior of amorphous and partially crystalline polymers are to appear frequently in this discussion. A partially crystalline polymer is defined as one which has a portion of its molecules packed close together as crystallites. On heating or cooling, this type exhibits a change of state and requires a heat of fusion to accomplish this change of state. It is illustrated in the specific heat curve for high density polyethylene shown in *Figure 1*. The heat of fusion is noted in the sharp increase in specific heat near the melting point (ca. 265°F.) of the polymer. Other partially crystalline (hereafter called crystalline) polymers discussed in this paper are low density polyethylene, and nylon.

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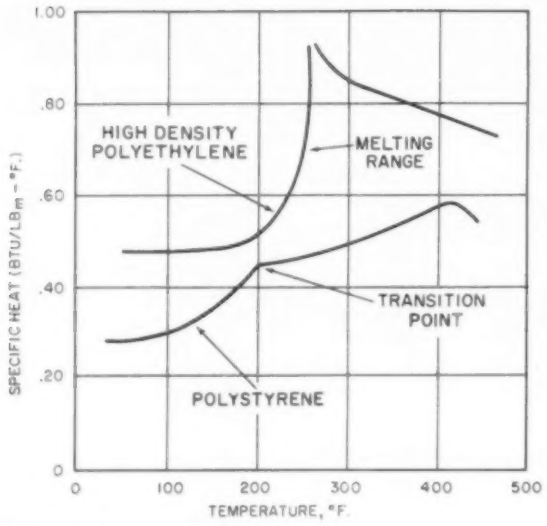

Figure 1. Specific heat vs temperature

Amorphous polymers, on the other hand, are highly branched, or have pendant groups which prevent them from crystallizing under normal conditions. These polymers do not exhibit a change in state on heating or cooling; they simply change in viscosity. They do have a "softening", or transition point where their thermal properties change somewhat. This is illustrated in the specific heat curve for polystyrene shown in *Figure 1*. The transition point appears at the change in slope of the curve at 200°F. Other amorphous polymers under discussion include high impact polystyrene, styrene-acrylonitrile copolymer, and polycarbonate.

Relation of Heating Behavior to Thermal Properties

A study was made of the heating (or plasticizing) behavior of four materials—a general purpose polystyrene, a high impact polystyrene, a 1.7 melt index, 0.92 density polyethylene, and a 3.5 melt index, 0.96 density polyethylene.

The techniques used to compare heating behavior were essentially those developed by Beyer and Dahl several years ago. They consist of measuring the temperatures of the heating cylinder and the material issuing from the nozzle at several throughput rates. From these data a quantity called "the heating efficiency" is determined. The heating efficiency is the ratio of the actual temperature rise of the material over the maximum theoretical temperature rise possible. It is expressed as follows:

$$\text{Percent Heating Efficiency (E)} = \frac{T_a - T_r}{T_c - T_r} \times 100$$

where T_a = material temperature
T_c = cylinder temperature
T_r = room or feed hopper temperature

It should be recognized this relation assumes that all of the temperature rise in the material is the result of heat conduction from the cylinder walls. This is not the case in actual practice since mechanical energy which is converted to heat is also introduced by the injection plunger. It is thus occasionally possible to realize an apparent heating efficiency greater than 100%.

To compare the heating behavior of the materials, a plot of percent heating efficiency vs throughput rate was made. Two criteria were used to compare heating behavior from such a plot. The first was to determine the throughput rate at an arbitrary heating efficiency. Others chose 80% heating efficiency as representative of that which occurs in quality molding. However, because of the excellent heating cylinder design of the machine used in this study, a heating efficiency as low as 80% was difficult to obtain with some materials. Thus, 90% heating efficiency was chosen as the basis.

Table 1. Heating Behavior of Various Molding Materials

	Machine: 8 oz. Impco					
Material	Exit Material Temperature at 90 lbs/hr Throughput Rate (°F)		Heating Efficiency at 90 lbs/hr Throughput Rate (percent)		Throughput Rate at 90% Heating Efficiency (lbs./hr.)	
Cylinder Temperature Settings, °F	400	500	400	500	400	500
Polystyrene	400	480	100	96	153	108
High Impact Polystyrene	397	471	97	94	143	108
Low Density Polyethylene	361	426	86	81	69	55
High Density Polyethylene	353	427	83	83	65	63

The second criterion was to choose an arbitrary throughput rate representing the molding production rate of the machine, and to compare materials on the basis of their heating efficiencies at this throughput rate. An 8–10 oz. Impco molding machine was used in this study, and the throughput rate selected was 90 pounds/hour. This equals a production rate of 120 dishpans per hour, which is typical of commercial production rates on a machine this size.

These methods were used to obtain data with the various materials at 400°F. and 500°F. heating cylinder settings. Heating cylinder temperatures and material temperatures were measured on potentiometers. A typical plot of heating efficiency vs throughput rate is shown in *Figure 2*. Percent heating efficiency data at 90 pounds/hour and throughput rate, pounds/hour, at 90% heating efficiency were obtained from plots such as *Figure 2*. These data are shown in *Table 1*.

The data in *Table 1* show the heating rate of polystyrene to be slightly higher than that of high impact polystyrene. At 400°F. cylinder setting, for example, the percent heating efficiency at 90 pounds/hour was 100% for polystyrenes and 97% for high impact polystyrene. Similarly, the heating rate of the low density polyethylene is about the same as the high density polyethylene. Their values for percent heating efficiency at 400°F. cylinder settings were 86% and 83% respectively.

Table 2. Thermal Diffusivity Data for Various Polymers

Material	Thermal Diffusivity, ft²/hr	Temperature Range, °F
Polystyrene	5.03×10^{-3}	25 to 450
High Impact Polystyrene	3.71×10^{-3}	25 to 450
Low Density Polyethylene	4.50×10^{-3}	325 to 500

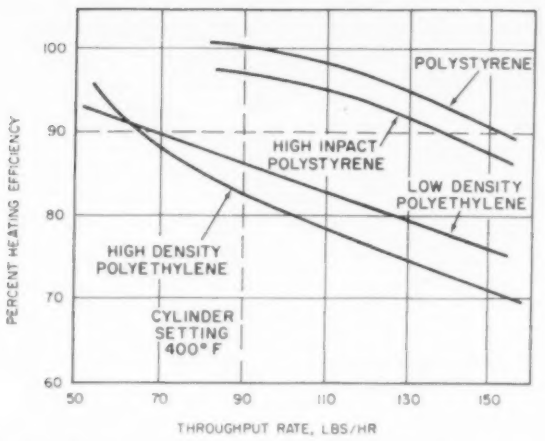

Figure 2. Percent heating efficiency vs throughput rate for various polymers

Table 1 significantly reveals that polystyrene materials have higher heating rates than do polyethylenes. The throughput rate data at 90% heating efficiency for polystyrene show it to be twice that of low density polyethylene. (153 vs 69 pounds/hour). The heating efficiencies at 90 pounds/hour throughput rate give a possibly more realistic comparison of the materials. The differences here are also quite significant—100% for polystyrene compared with only 86% for low density polyethylene.

The slower heating rates of the polyethylenes demand careful consideration of the plasticizing capacities of machines used to mold them. These polymers will probably be more apt to exhibit molding problems associated with poor plasticizing, problems such as difficulty in filling the mold, cold pellets in the molded part, poor welds, or poor molded strength.

To relate the actual heating rates in the molding machine to the thermal properties, consider the thermal diffusivity values shown in *Table 2*. Recall that thermal diffusivity describes the relative ability of a material to change temperature. The thermal diffusivity values for polystyrene and high impact polystyrene predict that polystyrene will heat roughly one-third faster than high impact polystyrene. This indicates a much greater difference in heating rate than was found experimentally. Part of this discrepancy is explained by the difference in flow properties between the two materials. High impact polystyrene is more viscous and requires more mechanical work to flow it through the heating cylinder than polystyrene. Thus, more mechanical work is converted to heat with the high impact polystyrene, and its actual heating rate increases until it is nearly equal to that of polystyrene.

The thermal diffusivity value for low density polyethylene does not correlate too closely with its actual heating rates obtained in the heating cylinder. For example, the thermal diffusivities predict that polystyrene will heat only very slightly faster than low density polyethylene, but actual results show that it heats much faster than polyethylene. The reason for this discrepancy is that the thermal diffusivity value for low density polyethylene covers only a range from 325 to 500°F. It does not include the melting temperature range where the specific heat of the polyethylene rises sharply due to the heat of fusion required for the change in state from crystalline to fluid. Although actual data are not available, one would expect the thermal diffusivity to decrease in the melting temperature range because of the increased specific heat.

Relating Thermal Properties to Cooling Rates in the Injection Mold

The cooling rate or "set-up time" in the mold is of major concern in injection molding. In molding operations where there is adequate heating capacity to plasticize the material properly, the set-up time becomes the controlling factor in determining the production rate.

Thermal data are useful in understanding, as well as predicting the comparative set-up times for various polymers. As in the preceding discussion of heating behavior, thermal data are more easily applied to amorphous polymers than to the crystalline polymers. In fact, Ballman and Shusman have applied unsteady-state heat transfer theory to permit quantitative predictions of set-up time for polystyrene.

Qualitatively, the set-up time for amorphous polymers is dependent on:

1. The thermal diffusivity of polymer.
2. The heat distortion temperature of the polymer.
3. The thickness of the molded part.
4. The mold temperature.
5. The material or "stock" temperature.

In terms of thermal properties, set-up time can be expected to decrease (1) as the thermal diffusivity increases, and (2) as the heat distortion temperature increases.

This same qualitative treatment can be given to crystalline polymers, except that crystalline melting point should be substituted for heat distortion temperature. Set-up time can be expected to decrease as the melting point increases.

Table 3 shows the approximate heat energies that must be removed in the mold in cooling various polymers from 500°F stock temperature to a 150°F. mold temperature. Note that in every case the heat to be removed is greater for crystalline polymers than for amorphous polymers. Thus, care must be taken to insure adequate cooling capacity in molds designed for use with crystalline polymers.

Uniformity of mold temperature is also a major consideration with crystalline polymers because of the dependency of the percent crystallinity on cooling rate. For example, if the mold temperature is non-uniform when molding high density polyethylene, the crystallinity will vary throughout the molded part and may result in differential shrinkage and warping. Highly crystalline areas in molded parts caused by slow cooling are associated with such quality problems as brittleness and environmental stress cracking of high density polyethylene.

Change in Volume with Temperature—Mold Shrinkage

Since injection molding involves cooling fluid polymer at high temperature to solid polymer at room temperature, it is important to know the change in volume that accompanies this temperature change. This is particularly true with regard to mold shrinkage.

Table 3. Heat Energy to be Removed in Cooling Various Polymers

Material	Polymer Type	Approximate Heat Energy to be Removed BTU/lb
Low Density Polyethylene	Crystalline	265
High Density Polyethylene	Crystalline	280
Nylon-6	Crystalline	270
Polystyrene	Amorphous	170
High Impact Polystyrene	Amorphous	170

Table 4. Mold Shrinkage of Various Polymers

Material	Polymer Type	Approximate Mold Shrinkage in/in	Relative Volume at 400°F
Nylon 66*	Crystalline	0.020	—
High Density Polyethylene	Crystalline 80-93%	0.020-0.050	1.27
Low Density Polyethylene	Crystalline 40-55%	0.015-0.030	1.22
Polystyrene	Amorphous	0.002-0.006	1.11
High Impact Polystyrene	Amorphous	0.002-0.008	1.11
Styrene Acrylonitrile Copolymer	Amorphous	0.002-0.005	1.16

* No Relative Volume Data

A plot of relative volume vs. temperature for various polymers is shown in *Figure 3*.

$$\text{Relative Volume} = \frac{\text{Volume at a given temperature}}{\text{Volume at room temperature}}$$

Because of the phase change that occurs in cooling crystalline polymers to room temperature, these polymers undergo a greater change in volume with temperature than amorphous polymers. Consequently, they would also be expected to have a higher mold shrinkage. For example, consider the case where a mold is being filled at a mass average temperature of 400°F.; in one case with polystyrene, in the other case with low density polyethylene. The relative volume data for these polymers at this temperature are 1.11 and 1.22 respectively. Therefore, one would expect the mold shrinkage to be much lower for the polystyrene than for the polyethylene.

Table 4 shows mold shrinkage and relative volumes, at a typical molding temperature, for various polymers. With the possible exception of styrene—acrylonitrile copolymer, relative volume data correlate with those for molded shrinkage.

The mold shrinkages of the crystalline polymers are considerably higher than those of the amorphous polymers. It should be noted that relative volume data do not quantitatively predict mold shrinkages. This is because of the effects of packing (flow into the mold after it is filled) and the compressibility of polymers.

Flow Properties

Most injection molding polymers, polycarbonates being the major exception, exhibit a high degree of non-Newtonian flow behavior. That is, their viscosity during flow is dependent on the shear rate (or the flow rate, for a given system) of the material. This is in direct contrast to Newtonian fluids such as water, oils, etc. whose viscosities are independent of shear rate. Thus, in defining the viscosity of a polymer, the shear rate as well as the temperature must be specified.

To illustrate non-Newtonian and near Newtonian flow behavior of polymers, flow tests were run on the standard melt index apparatus* for low density polyethylene, high density polyethylene, and polycarbonate. Standard conditions for melt index were used, with the exceptions that (1) one series of data was obtained at 10 times (440 psi) the normal melt index pressure (44 psi) and (2) a non-standard temperature of 260°C. was used to test polycarbonate. To give a rough indication of the degree of non-Newtonian flow behavior, the ratio of melt flow at 440 psi to melt flow at 44 psi was calculated. A Newtonian fluid will have a ratio of 10, since flow rate will be directly proportional to pressure. The data are shown in *Table 5*.

* See ASTM test D-1238-52T

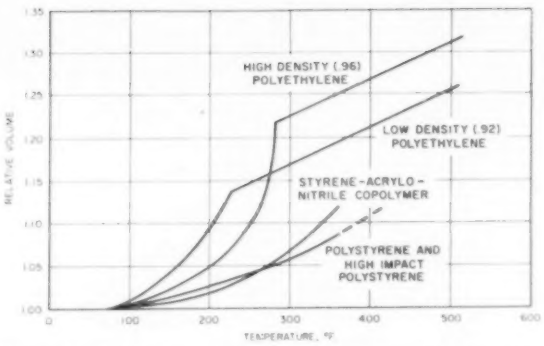

Figure 3. Relative volume vs temperature for various polymers

The flow of these three materials is nearly the same at the low shear rates obtained at 44 psi. However, because of their high degree of non-Newtonian behavior, the polyethylenes have much higher flow than the polycarbonate at 440 psi. These differences in flow behavior are even more apparent in an actual molding operation. Minimum pressure to fill a rectangular dishpan mold in an 8-10 oz. Impco was determined for the three materials. These data, shown in *Table 6*, indicate the pressure to fill to be much lower for the polyethylenes than for the polycarbonate. Keep in mind that at low shear rates, these materials had about the same flow behavior. These results demonstrate the importance of a high degree of non-Newtonian flow behavior on the ease of molding. They also indicate that melt index, or more generally, low shear rate flow tests, cannot be used to measure moldability.

Effect of Molecular Orientation on Molded Physical Properties

The orientation of the polymer molecules during flow is the basic mechanism used to explain the non-Newtonian flow behavior of polymers. At rest, the thread-like polymer molecules are coiled and entangled about one another. However, during flow the molecules uncoil and align themselves in the direction of flow. Such molecules readily slip over one another, thus reducing the polymer's effective viscosity.

The molecular orientation of polymers during flow also has a definite influence on molded physical properties as well as upon relative ease of processing. In general, this effect is to increase the mechanical strength in the direction of orientation at some sacrifice of mechanical strength perpendicular to the direction of orientation.

During flow from the heating cylinder to the mold, the molecules line up in the direction of flow. When this hot,

Table 5. Melt Flow Data for Various Polymers

	Melt Index Apparatus			
Material	Test Temp. °C	44 psi Melt Flow gms/10 min	440 psi Melt Flow gms/10 min	Flow Ratio
Polycarbonate	260	3.1	50	16.1
Low Density Polyethylene	190	4.3	258	60.0
High Density Polyethylene	190	2.2	189	86.0

Table 6. Pressure to Fill Data for Various Polymers

Mold: Rectangular Dishpan, 9-in. x 11-in. x 5-in. (high) x 0.080-in. thick). Machine: 8-10 oz. Impco

Material	Stock Temperature °F	Mold Temperature °F	Minimum Pressure to Fill (psi)
Polycarbonate	680	235	23,000
Low Density Polyethylene	535	130	7,600
High Density Polyethylene	535	130	11,500

oriented material strikes the mold surface, the orientation is frozen-in. The material in the mold remains oriented until the mold fills and the shearing action of flow stops. At this point the material in the mold begins to relax to a degree commensurate with the amount of cooling it has undergone. In the final molded part, this results in a thin, highly oriented layer below the surface followed by a layer of decreasing orientation to nearly random configuration at the center. Near the mold gate, it has been reported that a second layer of highly oriented material occurs due to flow during packing of the mold.

The effects of molecular orientation on the molded physical properties of polystyrene, styrene—acrylonitrile copolymer, high impact polystyrene, high density polyethylene, and polycarbonate are shown in *Table 7*. These data were obtained by taking test specimens in the direction of flow and perpendicular to flow from 5-in. x 20-in. x $\frac{1}{8}$-in. plaques which were molded in a 12-oz. Lester machine.

Polystyrene, styrene acrylonitrile copolymer, high impact polystyrene, and high density polyethylene generally have better physical properties in the direction of flow than perpendicular to flow. This is particularly true for the tensile strengths of polystyrene and styrene acrylonitrile copolymer, which are almost twice as high in the direction of flow, and the impact strengths of high impact polystyrene and high density polyethylene, which are three times as high in the direction of flow. Polycarbonate, however, shows equal tensile strength and equal impact strength in both directions. This is because of its low tendency to orient during flow.

In most cases, frozen-in molecular orientation reduces the practical strength of injection molded items. A typical example of this is the weakness across the direction of flow of injection molded polystyrene thin walled vending cups or pint containers. In specific cases, the mold gate can be located so that frozen-in molecular orientation can enhance the practical strength of the molded part. This involves using such molecular orientation to strengthen the part in the area which is expected to take most abuse in service.

Frozen-in molecular orientation also influences the molded shrinkage of injection molded pieces. Generally, shrinkage in the direction of flow is greater than that encountered perpendicular to flow. For example, studies with high density polyethylene show that molded shrinkage averages 0.031 inches/inch in the direction of flow, compared with only 0.023 inches/inch perpendicular to flow. Because crystalline polymers exhibit higher molded shrinkage than amorphous polymers, control of dimensions and warpage, or variation in shrinkage with direction of flow, becomes correspondingly more difficult with crystalline polymers.

We have seen, then, a demonstration of the ways in which injection molding behavior depends upon these basic flow and thermal properties. With the new understanding that these relationships provide, we can build better molds, better machines, we can achieve more desirable and controllable molding conditions. The rewards are not only greater productivity but also a better product.

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Table 7. Effect of Orientation on Molded Physical Properties

Mold: 5-in. x 20-in. x 0.125-in. center gated plaque
Machine: 12-oz. Lester

Material	Tensile Strength (psi)		Tensile Elongation (%)		Izod Impact Strength ft-lbs/inch of notch	
	∥ to Flow	⊥ to Flow	∥ to Flow	⊥ to Flow	∥ to Flow	⊥ to Flow
Polystyrene	6,400	3,700	1.6	0.9	0.32	0.20
Styrene Acrylonitrile Copolymer	10,200	5,200	2.2	1.0	0.35	0.27
High Impact Polystyrene	3,250	3,000	17.0	3.0	1.4	0.48
High Density Polyethylene	4,250	4,100	72	30	2.5	0.8
Polycarbonate	9,300	9,250	—	—	17	16

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Pitfalls in Predicting the Performance Characteristics of High Density Polyethylene

A testing program for evaluating processing characteristics and tensile properties, of high density polyethylenes

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During the past few years, high density polyethylene has assumed an important role in the plastics industry. Unfortunately, not all of the physical properties of polyethylene are improved by increasing the density. In several applications the products proved to be brittle, and both stress-cracking and thermal embrittlement severely limited its use. For a period of time the words, "high density polyethylene", were in ill repute because of their association with poor quality resins. It was not until it was recognized that a compromise must be sought between high density, high molecular weight and processing ease that "high density polyethylene" began to assume its rightful place in plastics technology.

The incorrect assumption that all high density polyethylenes are alike is still occasionally made. There are at least three broad methods for producing high density polyethylene on a commercial scale, and each results in significantly different physical and processing properties. In addition, the process variations utilized by the different producers result in significant differences in physical properties within a given production method. But, perhaps, of even greater importance is the difficulty in maintenance of product uniformity which results in significant lot-to-lot variations and a poor reputation for the polymer in general. As a result, there is a notion prevalent that an oversupply of high density polyethylene exists. It is true that an ample supply of high density polyethylene is available; but, simultaneously, there exists a critical shortage of high quality resin possessing both a favorable balance of properties and lot-to-lot uniformity.

BEST OF ANTEC!

How can this confused situation be clarified? The work here reported by Goodrich-Gulf Chemicals, Inc. indicates that the answer lies in establishing a suitable testing program. Polyethylene is a difficult polymer to characterize, and the improper use of test results can be more confusing than enlightening. Currently, entirely too much emphasis is placed on data from one-point test results. These tests are completely inadequate to differentiate between high density polyethylenes. Often, the assumption is made that data obtained in this manner on high density polyethylenes from different producers will predict the differences in processing and extended service life. Although many plastics engineers recognize the shortcomings of such assumptions, the testing inadequacies still exist and may result in considerable trouble. It is common to hear of the 30,000 pound lot that failed in a customer's plant or proved inadequate in field use. Such occurrences are both unnecessary and expensive, and can be avoided by utilizing the proper testing program.

The need for proper evaluation techniques is most important for high molecular weight polyethylene. High density polyethylenes of very high molecular weight possess excellent properties for extended service use but many present processing difficulties. To take advantage of these properties, it is imperative to predict properly the processing characteristics of the resins. By the proper use of presently available test methods, more accurate information can be readily obtained regarding processing characteristics, tensile properties and oxidation resistance.

Processing Characteristics

Efforts to correlate physical properties with crystallinity and molecular weight have met with some success (1, 2). Density has been used as a measure of the crystallinity of polyethylene. Correlation between the melt viscosity and the molecular weight has been established (3). Early in the evaluation of polyethylenes, the melt index—a measure of the fluidity of the melt—was introduced as a method of characterization and has enjoyed wide-spread acceptance since then (4).

However, the melt index measurement for characterizing polyethylene and, particularly, for predicting processing behavior has been under severe criticism for some time (5, 6, 7). The main criticism is that melt index measurements are made at a low rate of shear while the majority of processing operations take place at much higher rates of shear. The flow of molten polymer as a function of the rate of shear is often quite complex (8, 9) and, consequently, polymers having the same melt index values often behave quite differently at higher rates of shear (10, 11).

As a consequence of this behavior, flow measurements at higher shear rates are becoming more prominent but have not yet become standard test procedures. Because of the melt fracture phenomena—evidenced by roughness of the extrudate (8, 10, 14)—these measurements are also subject to criticism as a guide to processing behavior. For example, two polyethylenes may show melt fracture at quite similar shearing stresses but at widely different shearing rates. Because melt fracture results in rough, irregular extrudates, it severely limits the rate of useful output. It is often stated that within a family of high density polyethylenes supplied by a given manufacturer, the melt index or flow index measurement is an accurate guide to the processing behavior. This is definitely not true in all cases. In fact, it is not even necessarily true for any single high density polyethylene because of the common practice of blending to a particular melt index value. *Thus, the comparison of true melt-flow curves as a function of the shearing rate may be the less expensive practice even though it is more involved than the one point method.* In other words, spending more money for testing can save the cost of production rejects. *Figure 1* shows relationships between flow index and melt viscosity for different families of polyethylenes. Notice that the two families behave quite differently. The correlations drawn between the melt viscosity and other physical properties, particularly those that are rate dependent, must be subjected to careful scrutiny before any far-reaching conclusions are drawn.

The melt flow behavior of a series of high density polyethylenes was studied over a wide range of shear rates and temperatures under conditions of constant rate. With this technique the force required to extrude the polymer at a given temperature and rate is measured. Similar measurements have been reported by Merz (15). One flat entry die was used throughout the experiments. *Figure 2* summarizes a portion of the data where the loads required to

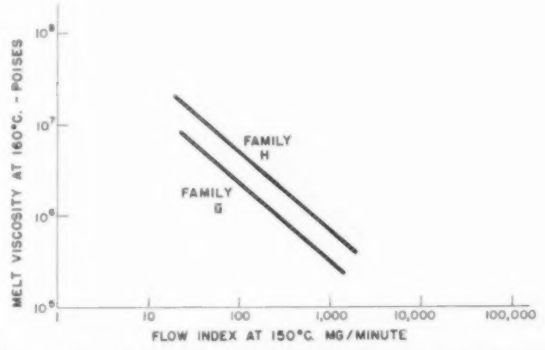

Figure 1. Relationship between melt viscosity and flow index for two polyethylene families

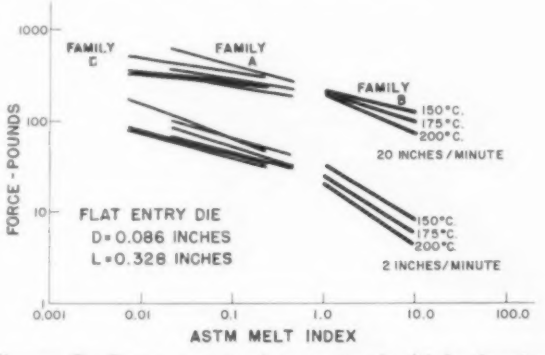

Figure 2. Force required to extrude high density polyethylene at given rate and temperature as a function of the ASTM melt index

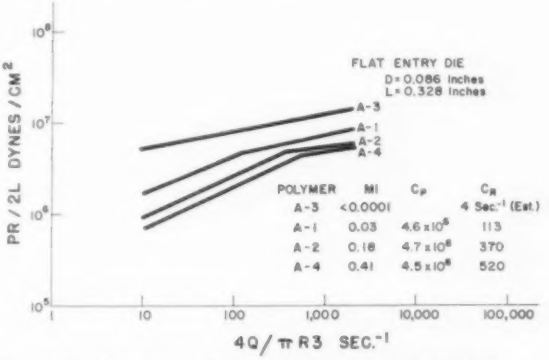

Figure 3. Melt flow data for family A at 175°C

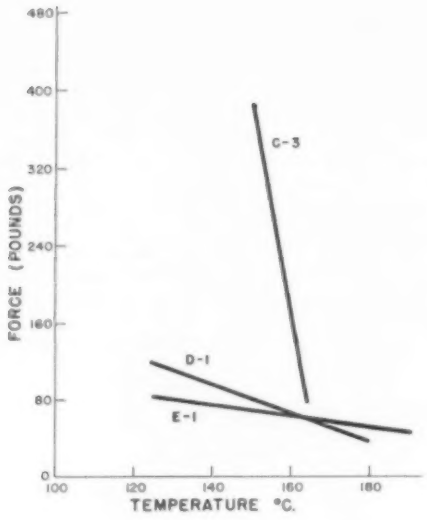

Figure 4. Effect of temperature on critical pressure

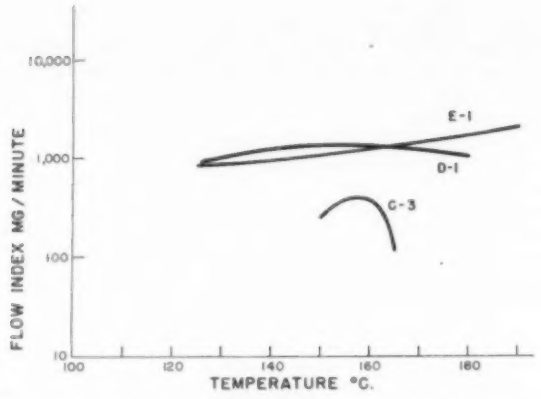

Figure 5. Variation in flow rate at critical pressure as a function of the temperature

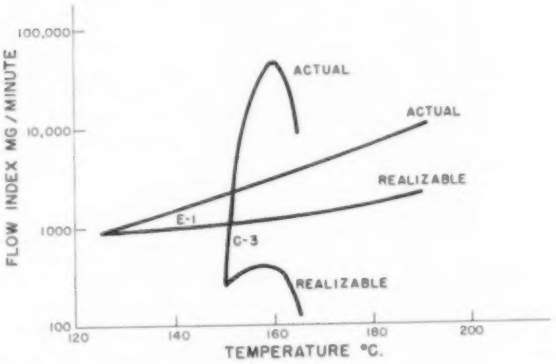

Figure 6. Effect of increasing temperature at constant pressure on extrusion output

extrude the various high density polyethylenes at two testing speeds and three temperatures are plotted as a function of the ASTM melt index value (18). At any testing speed and temperature, the data can be represented by a curve that decreases in slope as the melt index decreases, but the scatter is beyond that of experimental error. This scatter of data can be eliminated by grouping the polyethylenes into three families produced by three manufacturers. When evaluated in this manner, each family exhibits a different pattern of behavior. It is clearly evident that high density polyethylenes of similar melt index values produced by different manufacturers behave differently.

These data imply that rather significant, albeit subtle, structural differences exist between the various families of high density polyethylenes. As the shear rate is increased, a higher load is, of course, required to extrude the polyethylene. But the rate of increase of load is much less than the rate of increase of extrusion. This behavior is a function of the melt index of the polyethylene and, as these values decrease, the rate of increase in the load becomes even smaller. The net result is, that as the speed of extrusion is increased, the higher melt index polyethylenes tend to behave more like the low melt index polyethylenes. At higher rates of shear, the difference in extrusion output is not nearly so great as that implied by melt index measurements. In addition to the rate effects, each family of high density polyethylenes shows somewhat different temperature responses which also appear to vary somewhat as a function of the extrusion rate.

A somewhat different treatment of the data appears in *Figure 3*. Plots of shear stress vs shear rate at the wall of the capillary are shown for a family of high density polyethylenes varying widely in their melt index values. The point at which an abrupt change occurs in the shear stress/shear rate relationship is called the critical point. At this point a small increment in the shearing stress results in a large increase in the shearing rate. At or near this point, melt fracture occurs (8, 10, 14) and the extrudates become irregular. For this family of high density polyethylenes the shearing stress at the critical point is remarkably constant and independent of melt index. However, the critical shear rate does increase with increasing melt index values but at a lesser rate.

Data of this type yield considerable information concerning the extrusion process. In *Table 1* are listed the observed critical shearing stresses and rates at different temperatures for selected high density polyethylenes from various families. It is evident that patterns of behavior for the various families are quite different and within a given

Table 1. Critical Shear Stresses and Critical Shear Rates

Family A

Polymer Temperature	1 Stress Dynes/cm²	1 Rate sec⁻¹	2 Stress Dynes/cm²	2 Rate sec⁻¹	4 Stress Dynes/cm²	4 Rate sec⁻¹
150°C.	7.5×10^{5}	52	4.6×10^{5}	225	4.8×10^{5}	440
175	4.6×10^{5}	113	4.7×10^{5}	370	4.5×10^{5}	520
200	2.7×10^{5}	40	4.1×10^{5}	355	2.2×10^{5}	152

Family B

Polymer	1		2		4	
150°C.	3.9×10^{5}	420	3.6×10^{5}	690	4.5×10^{5}	150
175	3.8×10^{5}	770	3.3×10^{5}	680	4.5×10^{5}	205
200	3.7×10^{5}	970			4.2×10^{5}	260

Family C

Polymer	1	
150°C.	5.1×10^{5}	365
175	5.0×10^{5}	701
200	4.0×10^{5}	380

family the behavior is not necessarily consistent. Apparently, the variations within the polymerization system required to produce the range of present commercial high density polyethylenes result in quite significant structural changes not indicated by density and melt fluidity (or viscosity) measurements.

The influence of temperature was investigated in more detail using constant-load capillary rheometry techniques and plots of the critical load as a function of temperature for three widely varying polyethylenes are shown in *Figure 4*. In each case the critical stress decreased with increasing temperature, but the temperature sensitivity of the various polyethylenes is strikingly different. The critical stress of polyethylene C-3 is extremely temperature sensitive, while that of polyethylene E-1 is relatively insensitive. The data in *Table 1* indicate that extremes of this type can be found within a given family of high density polyethylenes.

However, of more practical importance is what happens to the extrusion rate as a function of the temperature. *Figure 5* shows the variation in the critical rate with temperature for the three polyethylenes discussed in *Figure 4*. The polyethylene, E-1, exhibiting the least variation in observed critical stress with increasing temperature shows a marked increase in critical rate with increasing temperature, a behavior which has been noted by others (8). For this polyethylene an increase in temperature will result in increased extrusion rates at lower pressures, a highly desirable situation. For polyethylenes C-3 and D-1, the critical extrusion rate passes through a maximum as a function of temperature. For the polyethylene showing the greatest variation in the pressure-temperature relationship, this maximum occurs within a very narrow temperature range, severely limiting operating conditions. The data of *Table 1* show that extreme variations in the critical rate-temperature relationship exist within a given family of high density polyethylenes as well as between the different families.

The severe limitation of melt fracture on extrusion processes is illustrated in *Figure 6*. Here, for polyethylene E-1, is shown what happens to the rate as the temperature is increased while maintaining constant pressure equal to that which produces melt fracture at 125°C. The upper line represents the actual output at any temperature but this output cannot be realized since the quality is limited by the melt fracture occurring and, thus, the true output is represented by the lower line. This lost output is even more striking for polyethylene C-3. The variations in the flow patterns of the different polyethylenes make either the melt index measurement, or a single flow index measurement at higher shear rates, inapplicable.

Figure 7 shows flow data obtained by constant-rate rheological techniques for three high density polyethylenes of similar melt index values, each manufactured by a different company. The differences are readily discernible; in critical shear stress they are not great, but in the critical shear rate they are quite large. Obviously, the melt index or flow index values are insufficient to describe the melt flow behavior of these polyethylenes. In addition, other physical properties are found to differ significantly among these three high density polyethylenes.

The degree of swell indicates that undisclosed process modifications, required to produce high density polyethylene of different melt index values, bring about subtle structure changes that are not indicated by melt index measurements. The extrudates invariably possess the shape of the orifice but are larger in diameter. The degree of swell is related to the visco-elastic properties of the melt and increases with the shear rate. The behavior observed is shown in *Figure 8* for the three high density polyethylenes of similar melt index values. The difference in the degree of swell between the three polyethylenes is quite striking. *Figure 9* shows the relationships between the degree of swell and the shear rate for the family of high density polyethylenes of varying melt index discussed earlier. Here, it is evident that the melt index bears little relationship to

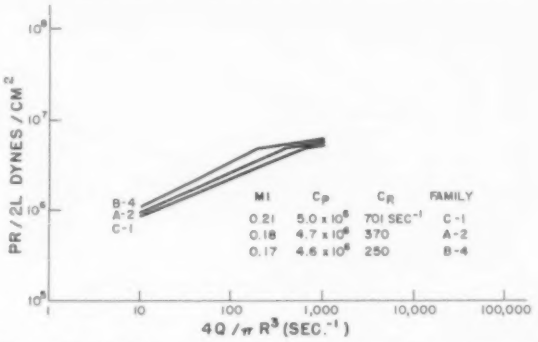

Figure 7. Melt flow data for polymers of similar melt index values

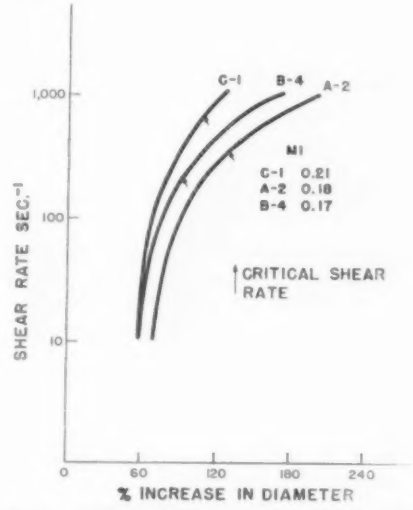

Figure 8. Increase in diameter of extrudate as function of shear rate

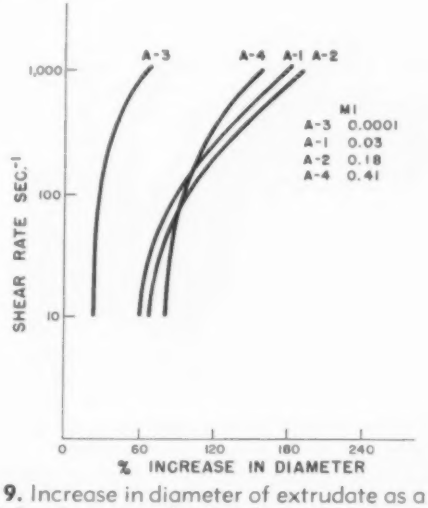

Figure 9. Increase in diameter of extrudate as a function of the shear rate for family A

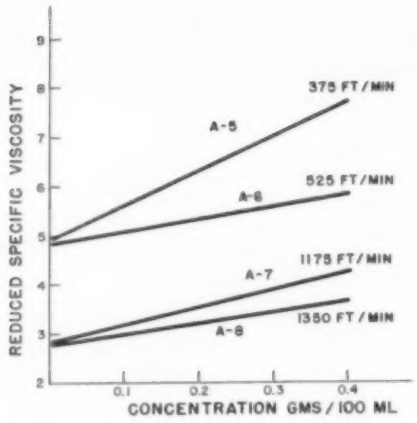

Figure 10. Intrinsic viscosity and extrusion speed

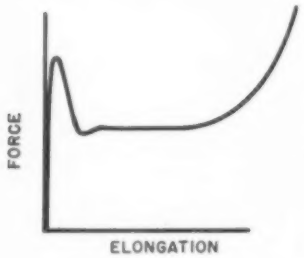

Figure 12. Typical force-elongation curve

the shear dependence of the visco-elastic properties of the polymer melt. The polyethylene of melt index 0.41 swells to the greatest extent at low shear rates, but is less sensitive to changes in shear rate. This behavior has been verified at other temperatures.

The literature is replete with excellent work relating the intrinsic viscosity of a polyethylene to its molecular weight, and such measurements have proved useful in characterization studies. However, unless these measurements can be related to some other properties or behavior, they are not very helpful to plastics process engineers. Many of the disadvantages of melt index measurements are applicable here as well. An example of the limitations of viscosity measurements is shown in *Figure 10*. The high density polyethylenes were extruded from a 2.5 inch extruder onto No. 20 wire with an 0.016 inch wall using a constant screw speed of 85 rpm.

Significant differences in extrusion speed are indicated for high density polyethylenes of the same intrinsic viscosity. For high density polyethylenes of the same intrinsic viscosity, the one with the lowest value for k′ in equation 1 extrudes at the faster rate.

$$\frac{\eta sp}{c} = [\eta] + k'[\eta]^2 c \qquad (1)$$

Equation 1 describes the solution viscosity data relationship. There exists a tendency to relate increasing values of k′ with increasing branching in the molecules, although the relationship is not considered too reliable. These data suggest that the more linear high density polyethylene extrudes at the faster rate. In any case, a careful study of dilute-solution properties must be made prior to any attempt to predict extrusion performance from such measurements.

Neither melt index nor intrinsic viscosity is sufficient to characterize a polyethylene. Often, however, significant information results from combining the data from the two tests. For example, in *Figure 11*, stress-cracking data are

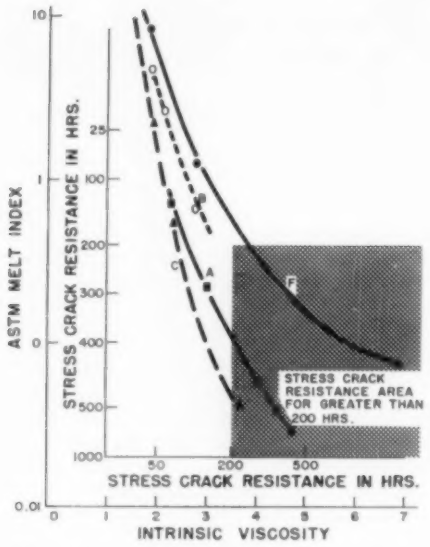
ASTM MELT INDEX
STRESS CRACK RESISTANCE IN HRS.
STRESS CRACK RESISTANCE AREA FOR GREATER THAN 200 HRS.
STRESS CRACK RESISTANCE IN HRS.
INTRINSIC VISCOSITY

Figure 11. Intrinsic viscosity vs. flow index

superimposed on a plot of melt index versus intrinsic viscosity for four families of high density polyethylenes. First, there is a wide variation among families in their respective intrinsic viscosity–melt index relationships—indicating that considerable structural variations exist between the families. In addition, the various high density polyethylenes possess widely different resistance to stress-cracking when compared on the basis of equivalent melt index values or equivalent intrinsic viscosities.

Tensile Properties

It is often stated that the tensile properties of polyethylenes either increase with, or are relatively unaffected by, an increase in the testing rates (13, 11, 16). Actually, however, the tensile properties of high density polyethylenes are extremely sensitive to the testing speed. In fact, it is possible to obtain almost any desired value by manipulation of the conditions of the test.

In the following examples, variations due to specimen size, imperfections, or improper molding have been minimized. The typical force-elongation plot obtained using a Mechanical Tate-Emery Testing Machine is illustrated in *Figure 12*. High density polyethylene can be considered to fail twice in tensile. After the initial rapid increase in the force required to extend the polyethylene to about 20 per cent elongation, the specimen yields and is easily extended

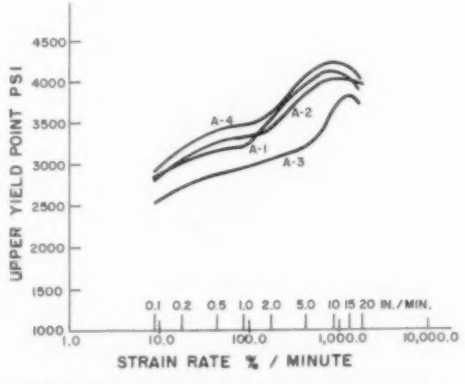

Figure 13. Effect of Strain rate on yield point

with negligible increase—sometimes even with a decrease —in the force required. This extension is non-recoverable and the specimen "necks". Eventually, an increase in force is required to elongate the specimen further and a region is reached in the force-elongation curve in which the high density polyethylene can almost be considered to follow Hooke's law. In this region, the force required to extend the specimen even relatively short distances is increasing rapidly.

The ultimate tensile strength is calculated conventionally, from the force required to rupture the specimen, but using the original cross-section. The specimen may break at the yield point, during the drawing period, or at any point past this region. Plots of the yield points and ultimate tensile strengths as a function of the strain rate in the test specimen for the family of widely varying melt index polyethylenes are shown in *Figures 13 and 14*. The strain rate varies with the specimen shape and, therefore, this method of representing the data is a better approximation of what is happening in the specimen than is the rate of jaw separation. This method also puts the data of various laboratories on a more nearly equal basis. For the ultimate tensile strength even this method of data representation is only an approximation. In some cases, it is impossible to restrict the elongation to the straight portion of the dumbbell and some necking is observed in the shoulders of the specimens. The yield strength passes through a maximum at a strain rate near 1000 per cent per minute and variations in yield strength of approximately 45 per cent are observed upon increasing the strain rate from 10 to 1000 per cent per minute. There are some differences in the response of the polyethylenes to the strain rate and the yield-strength maximum also varies to some extent. The greatest variation in the absolute values is found at a strain rate of 454 per cent.

The ultimate tensile strength of a given high density polyethylene exhibits an even greater variation with the strain rate. Like the yield strength, it also passes through a maximum, but the maximum occurs at much lower strain rates and is much more pronounced. The response of the various high density polyethylenes within this family to increasing rates of strain is strikingly different and in some instances the polyethylenes rupture during the "necking" period.

The relationships for still another family of high density polyethylenes appear in *Figure 15*. The same general sensitivity to strain rate is indicated, but there are striking differences between the two families. The maximum in the yield strength for family (B) as a function of the rate of strain is far more pronounced and is observed at a strain

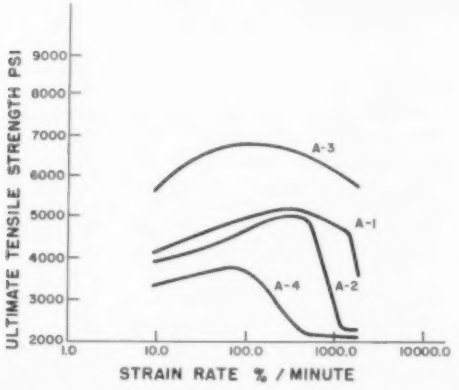

Figure 14. Ultimate tensile strength as a function of the strain rate for family A

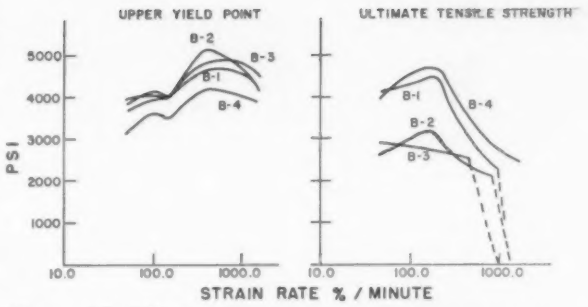

Figure 15. Effect of strain rate on tensile properties for family B

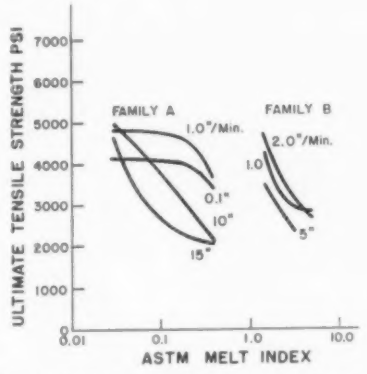

Figure 16. Ultimate tensile strength as a function of melt index

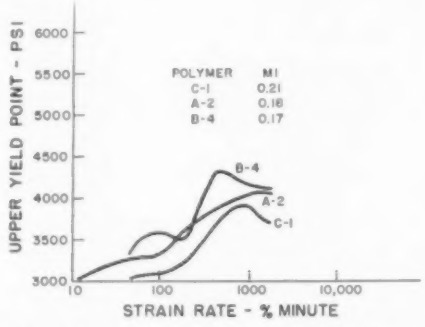

Figure 17. Effect of strain rate on yield strength for polyethylenes of similar melt index

rate of about one-half that observed for family (A). The relative insensitivity of the yield strength over the range of strain rates of 45 to 100 per cent per minute, is more pronounced for family (B) than for family (A); the data suggest that a second, but lower, maximum is present at a strain rate of about 90 per cent per minute. Additional data are required to ascertain the true behavior over this range as well as to determine if the yield strength again increases at strain rates over 2000 per cent per minute.

The behavior of the ultimate tensile strength of family (B) as a function of the strain rate is also quite dramatic. These high density polyethylenes exhibit a maximum in the ultimate tensile strength as a function of the strain rate, and the maximum occurs at a lower strain rate than for the high density polyethylenes of family (A). It is the behavior of the ultimate tensile strength past the maximum as the strain rate increases that contrasts so markedly with the behavior of family (A). At some rather critical rate of

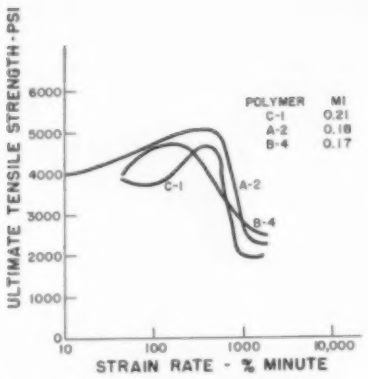

Figure 18. Effect of strain rate on ultimate tensile strength for polyethylenes of similar melt index

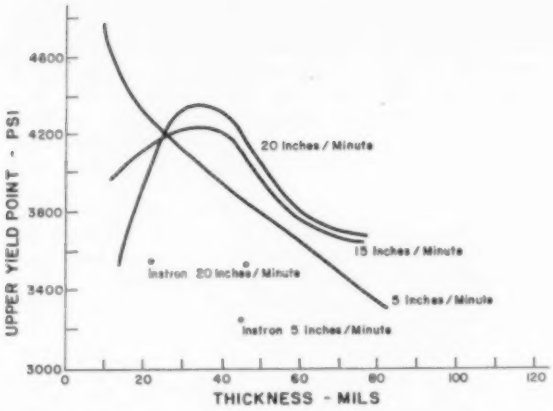

Figure 19. Upper yield point as a function of sample thickness

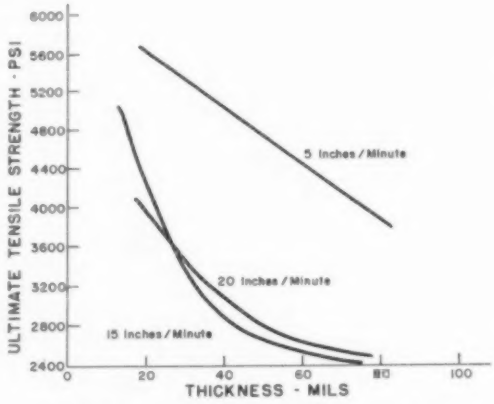

Figure 20. Ultimate tensile strength as a function of sample thickness

strain the polyethylenes rupture at, or just beyond, the yield point and necking is not observed.

At the commonly used testing speed of two inches per minute jaw separation, quite dissimilar polyethylenes may appear to be similar in their tensile properties. The ultimate tensile and elongation, in particular, are quite sensitive to strain rate and the high density polyethylenes can be distinguished by testing at speeds above 15 inches per minute. Rather good correlations can be found between the ultimate strength properties and such properties as flex fatigue and environmental stress-cracking.

For these reasons it is imperative to know the conditions under which the ultimate properties were determined to avoid possible misapplication of high density polyethylenes. Now, it is true that the literature contains correlations between ultimate strength properties and some measure of the molecular weight such as melt index, melt viscosity, or solution viscosity. But in view of the data presented here, such correlations appear to possess very limited applicability. For example, the tensile values for each family of high density polyethylenes as a function of the melt index are shown in *Figure 16* at various testing speeds. Any relationship established would be extremely limited in scope.

Data for the three high density polyethylenes of similar melt index are shown in *Figures 17 and 18*. The sensitivities of these polyethylenes to the strain rate and the actual tensile values involved are significantly different and strongly suggest that variations in final properties of finished articles can be anticipated.

Two additional points on tensile measurements should be made. First, some literature sources state that the testing rate has little effect on the tensile properties for thin specimens (11). This is definitely not the case for high density polyethylenes. Nakamora and Skinner have demonstrated that it is not even true for at least one low density polyethylene (17). Actually, a rather startling interaction occurs between the testing speed and the thickness of the test specimen. This is shown in *Figures 19, 20, and 21*. As the specimen thickness is decreased at testing speeds of 15 and 20 inches per minute, the yield strength increases rapidly and passes through a maximum for test specimens near 35 mils thickness. For thinner specimens the drop in yield strength is sharper at the higher testing speed. At the slower testing speed of 5 inches per minute a yield strength maximum is not observed at all over the thickness range investigated. The yield strength increases at an accelerating rate as the thickness is decreased, at least to 10 mils.

The ultimate tensile strength is observed to increase with a decrease in specimen thickness with no maximum value observed within the limits of the available data. Again, the data for this high density polyethylene show the highest values are obtained at five inches per minute. In view of the other data presented in this paper, data are now being obtained at lower testing speeds. The ultimate elongations pass through a maximum for specimen thicknesses of 30–40 mils at testing speeds of either five or twenty inches per minute. As in other cases, the testing speed of five inches per minute results in the higher values.

The second point to be mentioned is the effect of the testing machine. The data of *Figures 19, 20, and 21* were obtained using a Mechanical Tate-Emery Testing Machine. For comparison, the plots include data obtained with an Instron machine. Note that the yield strength values are appreciably lower when measured on the Instron machine. The values for ultimate tensile and ultimate elongation are in much better agreement for the two machines. This disagreement in the yield strength was traced to the recording mechanism, which had a full-scale response of two seconds. However, recorders are available with far faster responses and this discrepancy does not need to be a serious problem. Nevertheless, unless tensile value are reported as a function of the strain rate and the test specimen thicknesses are rigorously specified, test results are of little value in enabling processors to choose the proper high density polyethylene for their proposed applications.

It was pointed out earlier that certain high density polyethylenes rupture near the yield point when tested in ten-

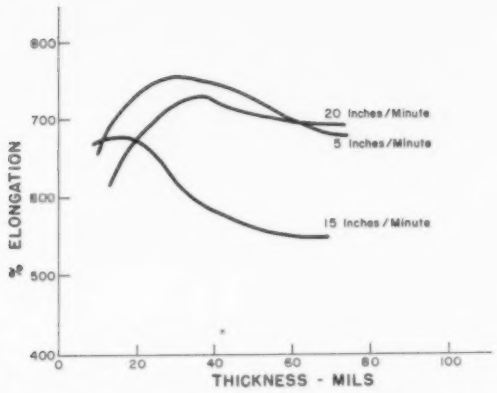

Figure 21. Ultimate elongation as a function of sample thickness

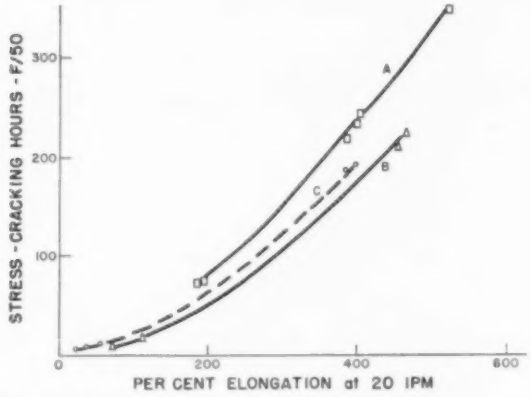

Figure 22. Stress crack resistance vs per cent elongation

sile at 20 inches per minute. However, when tested at two inches per minute the polymers are readily elongated well past the yield point. This behavior in tensile at the higher testing speed correlates with stress-cracking resistance and data for three families of high density polyethylenes are shown in *Figure 22*. Such a correlation has not been found for low density polyethylenes or at lower testing speeds. Once again, it is evident that the various families of high density polyethylenes behave differently and that attempts to choose the best polymer for any application on the basis of limited information is a truly dangerous practice.

Oxidation Resistance

It should be noted that resistance to oxidation is also a necessity for adequate product life. However, due to the subtle structural differences responsible for the types of behavior just discussed, polymer-antioxidant interactions also exist which result in widely varying life-spans for different high density polyethylenes. It is hoped that this important problem may be discussed in detail in a subsequent publication.

Summary

High density polyethylenes prepared by different manufacturers can possess quite different properties, although commonly used test methods may yield identical values. The utility of melt or flow index measurements in predicting processing behavior is extremely limited in scope due to shear effects and melt fracture. The determination of true melt flow curves at several temperatures is actually necessary to determine which polyethylene will yield the highest realizable output due to unpredictable variations in the critical rate with temperature. The prediction of extended service-life properties thought related to molecular weight from flow or viscosity measurements is extremely dangerous.

The tensile properties of high density polyethylenes are very sensitive to the rate of strain, and interactions also exist between the rate of strain and the thickness of the test specimen so that nearly any tensile value can be obtained, thereby making derived correlations with flow measurements of little value. Since the tensile properties pass through a maximum with increasing strain rates and drop off precipitously at some strain rate characteristic of each high density polyethylene, the data can be used to advantage only if the testing conditions are rigorously specified. High ultimate elongations at strain rates near 1000 per cent per minute correlate with resistance to environmental stress cracking.

To adequately characterize a polyethylene to avoid misapplication, it is necessary to determine the melt flow behavior at various shear rates and temperatures, behavior in tensile at various rates of strain, and the oxidation resistance. Single point measurements can lead only to serious problems, including failure of the final product in the field.

Acknowledgments

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Effect of Molding Conditions on Shrinkage of Modified Polystyrene

Molding conditions affect shrinkage of plastics. A study of these conditions on modified polystyrene shows that while dimensions were affected, the rate of shrinkage remained constant and independent

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Koppers Company, Inc., Plastics Division

Shrinkage has been defined (1) as the difference between corresponding linear dimensions of the mold and of the molded piece, those measurements being made at room temperature. This is a general definition and does not specify the time at which these measurements are to be made nor their accuracy requirements. It is well known that the shrinkage of plastics varies considerably. Phenolics, for example may shrink as little as 0.001 inches per inch, whereas polyethylene may shrink as much as 0.050 inches per inch. Modified or impact polystyrene has been found to shrink anywhere from 0.002 to 0.006 inches per inch when measured according to the ASTM method (2).

The effect of different molding conditions on the shrinkage of modified polystyrene was recently studied in detail. This study was brought about by problems encountered in the field. This problem was encountered while attempting to mold a large U-shaped breaker strip to be used in the assembly of a domestic refrigerator. The material being molded, labeled "Gamma", was a high impact polystyrene of the graft copolymer type. The breaker strip was molded according to previously established molding conditions which were found satisfactory for this particular material. When a new material, called "Alpha", was substituted, it was found impossible to produce satisfactory pieces. The difficulty encountered was the inability of the molder to remove the piece from the mold. On-the-spot changes in the molding conditions did not solve the problem. A subsequent close comparison of the acceptable and the unacceptable frames showed that the unacceptable were actually slightly longer than the acceptable. That is, they had shrunk less and thus were sticking in the mold. Therefore, it became obvious that the shrinkage characteristics of the acceptable material were different from those of the new material. A decision was made to conduct a number of experiments in order to determine if shrinkage could be controlled, and which phases of the molding operation were the most influential in changing the amount and the rate of shrinkage of modified polystyrene.

A short survey of the literature on shrinkage did not present a ready solution to the problem. Although a number of articles (3, 4, 6, 7, 8, 9, 10, 11) have appeared recently dealing with the flow of plastics into molds, and methods for overcoming sinks and voids in thick-section moldings, little additional information other than that presented several years ago in an article (5) on mold shrinkage of thermoplastic materials could be extracted from the literature. It was, therefore, decided to proceed with the investigation on shrinkage by determining the effects of varying the conditions used to mold a simple, single-gated 5-inch x ½-inch x ½-inch test bar on the dimensional changes of the bar while it cools after removal from the mold. This procedure differed from that advocated by the American Society for Testing Materials (2) in that the in-

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Table 1. Effect of Cylinder Temperature on Shrinkage of Molded Bars*

Material	Time Interval after Ejection (Minutes)	Dimensions of Nominal 5" x ½" x ½" Bars at Indicated Times: 300°F. Cylinder Temperature	330°F. Cylinder Temperature	360°F. Cylinder Temperature
Alpha	0.5	5.036	5.042	5.044
	1.5	5.026	5.031	5.033
	3.0	5.021	5.024	5.026
	4.5	5.018	5.019	5.021
	6.0	5.015	5.016	5.018
	7.5	5.013	5.014	5.016
	9.0	5.012	5.012	5.014
	10.5	5.011	5.011	5.013
	12.0	5.010	5.010	5.012
	13.5	5.010	5.010	5.011
	Initial Dimensions of Bars Varied:	+0.002 −nil	±0.001	+0.001 −nil
Gamma	0.5	5.030	5.038	5.043
	1.5	5.020	5.028	5.033
	3.0	5.014	5.022	5.026
	4.5	5.009	5.017	5.021
	6.0	5.006	5.013	5.018
	7.5	5.004	5.010	5.015
	9.0	5.002	5.008	5.014
	10.5	5.001	5.007	5.012
	12.0	5.000	5.007	5.011
	13.5	5.000	5.006	5.010
	Initial Dimensions of Bars Varied:	±0.001	+0.002 −nil	+0.001 −nil

* Inside Dimension of Hot Cavity: 5.028 inches

terest lay in the shrinkage which takes place within the first 10 to 15 minutes after injection, whereas the method of ASTM is concerned with shrinkage which occurs from 4 to 6 hours, after 24 hours and after 48 hours.

Experimental Details

In order to determine if the amount and rate of shrinkage of the two materials differed one from the other, a number of measurements were carried out on 5-inch x ½-inch x ½-inch ASTM flex bar specimens molded on an 8-ounce Reed Prentice Model 10-D-8 injection molding machine. The experimental data obtained are shown in *Tables 1 through 7*.

Materials Examined. The materials examined were modified polystyrene labeled "Alpha", the material which proved to be unacceptable in the aforementioned molding trial, and modified polystyrene labeled "Gamma", which was acceptable. Both of these materials were styrene-butadiene graft copolymers prepared in commercial equipment.

Molding Conditions. *Table 9* contains details of the molding conditions used in six experimental series. It will be noted that each member of this series differs from the other members by the change of one variable only. It was considered important to minimize the number of variables being studied and to eliminate, as much as was possible, the compounding of variables. Thus, no effort was made to mold the specimens at the minimum or optimum cycle since this would have necessitated the change of more than one condition from experiment to experiment.

Measurements Made. The specimen lengths were determined with a 5-inch micrometer immediately after removing the test bar from the mold, then 1.5 minutes after ejection and every 1.5 minutes thereafter until ten measurements had been obtained.

In addition to the measurements made on a particular bar as it cooled, the lengths of nine additional bars were determined within 60 seconds after each bar was removed from the mold. These measurements were made to determine the variation of bar length from sample to sample.

In order to determine whether shrinkage of the major axis would result in an increase in the minor axis of the

Table 2. Effect of Cylinder Temperature on Physical Characteristics of Molded Bars

Material	Cylinder Temperature (°F.)	Average Width of Bars (in.)	Average Weight of Bars (gms.)	Specific Gravity* of Bars (23°C.)
Alpha	300	0.499	21.5437	1.055
	330	0.501	21.6402	1.056
	360	0.499	21.6736	1.056
Gamma	300	0.500	21.6821	1.070
	330	0.500	21.8344	1.070
	360	0.501	21.8949	1.070

* Polymer Specific Gravities: Alpha—1.058, Gamma—1.071

Table 3. Effect of Mold Temperature on Dimensions of Bars

Material	Time Interval after Ejection (Minutes)	Mold Temperature: 100°F.	120°F.	150°F.
Alpha	0.5	5.045	5.045	5.041
	1.5	5.041	5.037	5.032
	3.0	5.035	5.032	5.024
	4.5	5.031	5.028	5.019
	6.0	5.027	5.024	5.015
	7.5	5.024	5.022	5.012
	9.0	5.023	5.022	5.010
	10.5	5.022	5.019	5.008
	12.0	5.021	5.018	5.007
	13.5	5.021	5.017	5.006
	Initial Dimensions of Ten Sample Bars Varied:	±0.001	+nil −0.001	+nil −0.001
Gamma	0.5	5.039	5.042	5.041
	1.5	5.036	5.038	5.036
	3.0	5.031	5.032	5.029
	4.5	5.026	5.028	5.024
	6.0	5.022	5.024	5.020
	7.5	5.020	5.021	5.017
	9.0	5.018	5.019	5.015
	10.5	5.017	5.018	5.013
	12.0	5.016	5.016	5.012
	13.5	5.015	5.015	5.011
	Initial Dimensions of Ten Sample Bars Varied:	+nil −0.001	+nil −0.001	+nil −0.001

Table 4. Effect of Booster Time on Dimensions of Bars

Material	Time Interval after Ejection (Minutes)	Booster Time 1.5 sec.	3.0 sec.	5.0 sec.
Alpha	0.5	5.039	5.040	5.042
	1.5	5.033	5.034	5.036
	3.0	5.027	5.027	5.028
	4.5	5.022	5.021	5.022
	6.0	5.018	5.018	5.018
	7.5	5.016	5.016	5.015
	9.0	5.014	5.014	5.013
	10.5	5.013	5.012	5.012
	12.0	5.012	5.011	5.011
	13.5	5.011	5.010	5.010
	Initial Dimensions of Bars Varied:	+0.001 −nil	+nil −0.001	+0.001 −nil
Gamma	0.5	5.037	5.037	5.042
	1.5	5.033	5.034	5.037
	3.0	5.028	5.028	5.031
	4.5	5.023	5.023	5.025
	6.0	5.019	5.019	5.022
	7.5	5.016	5.016	5.019
	9.0	5.015	5.015	5.017
	10.5	5.013	5.014	5.016
	12.0	5.012	5.012	5.014
	13.5	5.011	5.012	5.014
	Initial Dimensions of Bars Varied:	+0.002 −nil	+0.002 −nil	+nil −0.001

Table 5. Effect of Injection Pressure on Dimensions of Bars

Material	Time Interval after Ejection (Minutes)	Injection Pressure 650 psig	850 psig	1,000 psig
Alpha	0.5	5.029	5.039	5.038
	1.5	5.024	5.031	5.029
	3.0	5.021	5.026	5.025
	4.5	5.016	5.024	5.021
	6.0	5.010	5.019	5.018
	7.5	5.008	5.017	5.016
	9.0	5.007	5.015	5.016
	10.5	5.005	5.014	5.014
	12.0	5.004	5.013	5.013
	13.5	5.004	5.012	5.013
	Initial Dimensions of Bars Varied:	+0.001 −nil	+nil −0.001	+0.003 −nil
Gamma	0.5	5.027	5.037	5.041
	1.5	5.020	5.030	5.034
	3.0	5.014	5.024	5.029
	4.5	5.011	5.020	5.025
	6.0	5.009	5.017	5.022
	7.5	5.007	5.015	5.020
	9.0	5.005	5.014	5.018
	10.5	5.004	5.013	5.016
	12.0	5.003	5.012	5.015
	13.5	5.002	5.011	5.015
	Initial Dimensions of Bars Varied:	+0.002 −nil	+0.001 −nil	+0.002 −nil

bar, the width of each of the ten bars was measured in the same manner. These data are shown in *Table 2*.

The weights of five bars chosen at random from each of the six sets of specimens obtained from the first experiment were determined on an analytical balance 24 hours after the bars were molded. These are shown in *Table 2*.

In addition, the specific gravities of the injection molded bars as well as those of the polymers themselves were determined in order to find out if voids or bubbles were present in the specimens, and if any changes in specific gravity had been brought about by the variations in the cylinder temperatures used to mold the first series of specimens. (*Table 2*).

Molding Conditions—Effect on Length and Shrinkage

Effect of Cylinder Temperature on Length of Bars. Comparing the actual lengths of these specimens upon removal from the cavity, the "Alpha" bars are slightly longer than the "Gamma" bars. The greatest difference of length occurs at the lowest cylinder temperature, while the difference is quite small at the highest.

Effect of Mold Temperature on Length of Bars. Considering that the inside dimension of the hot cavity is 5.028-inches, the "Alpha" material expands or "balloons" considerably more upon removal from the mold than does the "Gamma" material. Changes in mold temperature markedly influence the dimensions of the molded bars. When the mold temperature is increased from 100 to 150°F., the bars become shorter. This is especially marked in the case for the "Alpha" material. The "Gamma" material does not appear to be influenced very greatly by changes in mold temperatures. The initial dimensions of the bars are, for all intents and purposes, the same regardless at what temperature the mold was held. Thus, it appears that a cool mold should be chosen in order to minimize the change in dimension with cooling time.

Effect of Booster Time on Length of Bars. The final dimensions of the specimens are in approximately the same order of rank as the initial dimensions. The bars which were the shortest at the beginning of the cooling period remained the shortest at the end of the cooling period. The booster time was varied from 1.5 seconds to 5.0 seconds. These changes had no effect on the shrinkage of either material. The post-expansion of both materials was the same regardless of the conditions used, as was the final length of the six types of specimens.

Effect of Injection Pressure on Shrinkage. As the injection pressure is increased from 650 psi to 1000 psi, the initial length and the final length of the pieces increase. That is to say, with greater pressures, the plastic is more and more compressed and thus balloons to a greater extent immediately after removal from the mold. However, its final length also remains greater than when it is molded at lower injection pressures. No significant differences were noted between the "Alpha" and the "Gamma" materials.

Effect of Feed Cushion on Shrinkage. As was the case with changes in cylinder temperature and changes in mold temperature, changing the feed cushion affects the shrinkage characteristics of the "Alpha" and "Gamma" materials in a different degree. As far as the "Gamma" material is

Table 6. Effect of Feed Cushion on Dimensions of Bars

Material	Time Interval after Ejection (Minutes)	Feed Cushion 0.125 inch	Feed Cushion 1.00 inch
Alpha	0.5	5.041	5.041
	1.5	5.032	5.030
	3.0	5.026	5.022
	4.5	5.020	5.017
	6.0	5.016	5.013
	7.5	5.013	5.010
	9.0	5.012	5.007
	10.5	5.010	5.005
	12.0	5.009	5.004
	13.5	5.008	5.003
	Initial Dimensions of Bars Varied:	+nil −0.001	+nil −0.001
Gamma	0.5	5.043	5.042
	1.5	5.037	5.037
	3.0	5.030	5.031
	4.5	5.026	5.026
	6.0	5.022	5.022
	7.5	5.019	5.019
	9.0	5.017	5.017
	10.5	5.015	5.015
	12.0	5.014	5.015
	13.5	5.013	5.014
	Initial Dimensions of Bars Varied:	+nil −0.001	+nil −0.001

Table 7. Effect of Ram Forward Time on Dimensions of Bars

Material	Time Interval after Ejection (Minutes)	Ram Forward Times—Injection and Cooling Periods 20-45 sec.	20-55 sec.	20-60 sec.	30-50 sec.
Alpha	0.5		5.041	5.043	5.042
	1.5	Samples	5.030	5.036	5.036
	3.0		5.021	5.029	5.030
	4.5		5.016	5.024	5.024
	6.0	Warped	5.012	5.021	5.020
	7.5		5.008	5.017	5.017
	9.0		5.005	5.015	5.015
	10.5	Excessively	5.003	5.013	5.013
	12.0		5.002	5.012	5.012
	13.5		5.001	5.012	5.012
		Dimensions of Bars Varied:			
		Not Measurable	+nil −0.001	+nil −0.001	+0.001 −nil
Gamma	0.5	5.042	5.042	5.042	5.042
	1.5	5.037	5.037	5.037	5.037
	3.0	5.030	5.032	5.031	5.030
	4.5	5.024	5.026	5.025	5.025
	6.0	5.020	5.022	5.021	5.021
	7.5	5.016	5.019	5.019	5.019
	9.0	5.013	5.017	5.017	5.017
	10.5	5.011	5.015	5.016	5.015
	12.0	5.010	5.014	5.015	5.014
	13.5	5.009	5.013	5.014	5.014
		Dimensions of Bars Varied:			
		+nil −0.001	+nil −0.001	+nil −0.001	+nil −0.001

concerned, the feed cushion change from 1-inch to ⅛-inch does not alter the initial or the final dimensions of the specimen. With the "Alpha" material, however, increasing the feed cushion produces more shrinkage. That is to say, the specimen made with the 1-inch feed cushion is shorter than that made with the ⅛-inch feed cushion.

Effect of Plunger or Ram Forward Times on Shrinkage. With one exception, changing the injection period and the cooling period does not appear to affect the shrinkage of either "Alpha" or "Gamma" specimens. The exception is "Alpha" molded at minimum ram forward times. Thus, it appears that the "Alpha" material is more sensitive to changes in the molding cycle. This is further brought out by the fact that samples molded with a short injection period and a short cooling period could not be measured properly since excessive warpage occurred, indicating the material was not properly cooled in the mold. The same effect, although in a lesser degree, was noted when the same injection period was maintained but the cooling period was increased from 45 seconds to 55 seconds. It will be noted that at these conditions the "Alpha" specimen shrank considerably, whereas the "Gamma" specimen exhibited normal shrinkage.

Effect of Molding Conditions on Rate of Shrinkage. As is shown in *Figure 2* and *Table 8* the rate of shrinkage when normalized, as indicated by the calculations which follow, is approximately the same for both materials regardless of the conditions under which they were molded. This finding is not totally unexpected since both materials belong, broadly speaking, to the same class of plastics and are expected to behave in a similar manner, assuming that they have the same coefficient of thermal expansion with time. In general, the rate of shrinkage as a function of time is similar for both materials. However, there are some notable exceptions. These are: The "Alpha" material is molded at high temperatures (*Table 1*); The "Alpha" material molded at 300°F., the lowest of the three cylinder tem-

Table 8. Normalized Shrinkage at Three Different Cylinder Temperatures*

Time Interval after Ejection (Minutes)	ALPHA Cylinder Temperature 300°F.	330°F.	360°F.	GAMMA Cylinder Temperature 300°F.	330°F.	360°F.
0.5	1.000	1.000	1.000	1.000	1.000	1.000
1.0	0.806	0.813	0.819	0.800	0.781	0.787
1.5	0.615	0.656	0.667	0.667	0.688	0.696
3.0	0.423	0.438	0.455	0.467	0.500	0.485
4.5	0.309	0.281	0.303	0.300	0.344	0.334
6.0	0.192	0.182	0.212	0.200	0.218	0.243
7.5	0.115	0.121	0.151	0.133	0.125	0.151
9.0	0.077	0.061	0.091	0.067	0.063	0.121
10.5	0.038	0.030	0.061	0.033	0.030	0.061
12.5	—	—	0.030	—	—	0.030

* Normalized Shrinkage $= \frac{Y - Y_\infty}{Y_o - Y_\infty}$

where Y_∞ = Final Dimension of Specimen
Y_o = Initial Dimension of Specimen
Y = Actual Dimension of Specimen at Time "T"

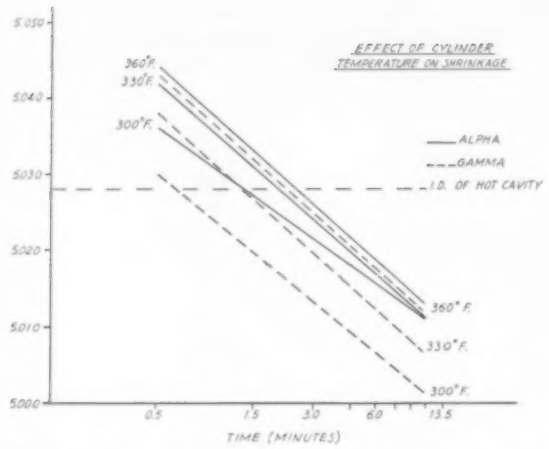

Figure 1. Effect of cylinder temperature on shrinkage

peratures chosen (*Figure 1*); The "Alpha" material molded with the minimum ram forward time.

When we look at these different rates, it becomes quite obvious that the "Alpha" material appears to be more sensitive to the different molding conditions used in this study. It further becomes noticeable that, of all the variables studied, those dealing with changes in the cylinder temperature and the mold temperature are the most influential as far as rate of shrinkage is concerned. This finding is somewhat at variance with that given in Reference (1) which states that: "Shrinkage is not materially affected by change in mold temperature." It is, of course, possible that the measurements conducted in this study deal with much smaller changes, taking place in the initial period of the shrinking phenomena and are, therefore, at variance with the findings discussed in the above reference.

An attempt was made to calculate the equations of the lines shown in *Figure 1* and to arrive at a general expression for these curves. The calculation follows:

General Form:

$$X = ae^{bY} = e^{b(Y - Yx=1)}$$

$$\ln X = \ln a + bY, \text{ therefore,}$$

$$Y = \frac{1}{b}\ln X - \frac{\ln a}{b}$$

$$Y = B(\log X) + A, \quad \text{where } B = \text{slope}, \quad A = \text{intercept}$$

$$\frac{1}{b} = \frac{\Delta Y}{\Delta(\log X)}$$

$$-\frac{\ln a}{b} = A = Yx = 1$$

$$\ln a = -b\,Yx = 1,$$

and summarizing, $a = e^{-b\,Yx=1}$,

$$b = \frac{\Delta(\log X)}{\Delta Y}$$

and $X = e^{-bYx=1}\ e^{bY} = e^{b(Y - Yx=1)}$

Then, considering the actual data,

γ at 300°F.

$$b = \frac{\log 1 - \log 13.5}{5.024 - 5} = \frac{0 - 1.13}{0.024} = -47.1$$

$$a = e^{(47.1)(5.024)} = e^{236}$$

Therefore, $X = e^{-47(Y - 5.024)}$

for γ at 330°F.

$$X = e^{-47(Y - 5.011)}$$

and for γ at 360°F.

$$X = e^{-47(Y - 5.000)}$$

Since these calculations show that the slope of γ_{300}, γ_{330} and γ_{360} are quite similar, an attempt was made to normalize these slopes and arrive at an overall expression for the shrinkage rate of these materials between times t = 0.5 and t = 13.5.

Let $Y\infty = 5.000$

Y mold = 5.028

$$\text{Then } \frac{Y\infty}{Y\,\text{mold}} = \text{fixed}$$

$$\text{and } \frac{Yo}{Y\,\text{mold}} = \text{variable}$$

$$Y - Y\infty = ae^{-bx},\ x = t$$

$$Yo - Y\infty = a$$

$$Y - Y\infty = Yo - Y\infty\ e^{-bt}, \text{ thus summarizing}$$

$$\frac{Y - Y\infty}{Yo - Y\infty} = e^{-bt}$$

The values for this expression were obtained from the data shown in *Tables 1, 3 to 7* and a portion of the results are presented in *Table 8* for the series on the effect of three different cylinder temperatures. These values were plotted and the Normalized Shrinkage Rate curve shown in *Figure 2* was obtained. As indicated on the graph, a fairly good fit is obtained, especially when "t" is smaller than 7.5 This indicates that the initial shrinkage rate of materials "Alpha" and "Gamma" is the same regardless which molding conditions were used to form the specimens.

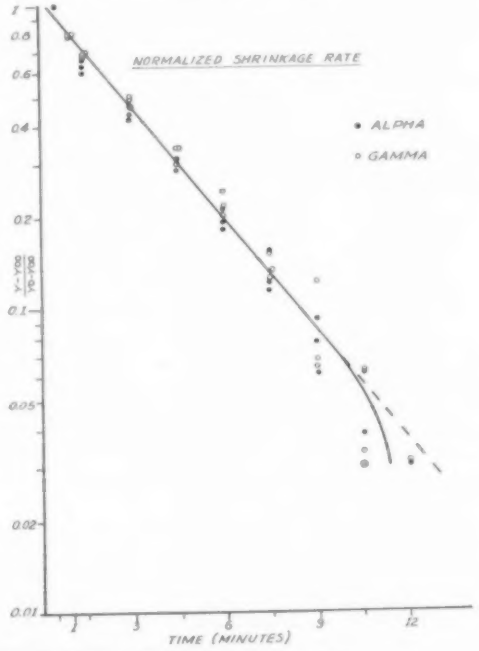

Figure 2. Normalized shrinkage rate

Cylinder Temperature—Effect on Weight and Specific Gravity of Molded Specimens

As mentioned earlier, the average weight of five bars of each material molded at the three different cylinder temperatures was determined, (*Table 2*). The results show that the average weight of the bars increases significantly when higher cylinder temperatures are employed. This result is expected since, at higher cylinder temperatures, more material can be packed into the mold since the material in the mold "freezes" more slowly, allowing an additional quantity of polymer to be injected into the mold to occupy the space vacated by the cooling and shrinking material. The data also show that the "Gamma" material is more amenable to the packing operation since the weight of the "Gamma" bars is greater than that of the "Alpha" bars. That differences in packing occur during this study is further borne out by the fact that when the materials were molded at increasing injection pressure, the initial sizes of the bars increased when higher pressures were used. Post-expansion thus was more prevalent at these higher pressures. The specific gravities of the bars which were weighed in this study were then determined and the data are shown in *Table 2*. These specific gravity results show, as expected, that they are independent from the cylinder temperatures used to mold the specimens. These results also indicate that the bars were molded free of bubbles and voids. The differential shrinkage of the "Alpha" and the "Gamma" specimens is probably related to the differences in specific gravity of the two polymers. The "Gamma" polymer was found to have a higher specific gravity. Since it is denser, it is quite possible that bars molded from this material post-expand to a lesser degree upon removal from the mold. This, then, would account for the fact that, in many cases, the "Gamma" specimens were shorter than the "Alpha" specimens; and, since the shrinkage rate of the two materials is practically identical, the final sizes of the bars molded from the two materials are probably predetermined by their initial size immediately after their removal from the mold. This also would account for the problems encountered in the field trial described. Based on the work in this study, the sticking of the part molded from "Alpha" at the conditions used to mold "Gamma" would result in "Alpha" being slightly larger than the "Gamma" part and thus it would be difficult, if not impossible, to remove from the mold. If, in this trial, the cylinder temperature would have been raised about 55°F., equal post-expansion could probably have been achieved and removal difficulty lessened.

Summary and Conclusions

The shrinkage of molded bars of two high impact rubber-modified graft copolymers was studied by determining the effects of different molding conditions on the dimensions of the parts, on their rate of shrinkage and on the weight of the pieces. It was determined that changes in the molding conditions affect the dimensions of the pieces but that their rate of shrinkage with time is constant and independent of these conditions. Certain variations in the molding conditions affect the initial dimensions of the bars more than others. These are changes in the cylinder temperature, the mold temperature and the injection pressure. Changes in the feed cushion, booster time, and the injection and cooling periods affected the lengths of the pieces in a lesser degree. Low temperatures and lower pressures reduced the initial lengths of the bars. The weight of the pieces increased with increasing cylinder temperatures although their density remained constant.

Acknowledgments

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Table 9. Molding Conditions Used in Experimental Series

Conditions	Series	Effect of Cylinder Temperature	Effect of Mold Temperature	Effect of Booster Time	Effect of Injection Pressure	Effect of Feed Cushion	Effect of Ram Forward Time
Cylinder Temperature (°F.)		300, 330, 360	360	360	360	360	360
Mold Temperature (°F.)		140	100, 120, 150	140	140	140	140
Injection Pressure (psig)		1,000	1,000	1,000	650, 850, 1,000	1,000	1,000
Molding Cycle (seconds):							
Injection		25	25	25	25	25	20-30
Cool		55	55	55	55	55	45-60
Delay		5	5	5	5	5	5
Booster Set		7	7	1.5, 3, 5	7	7	7
Overall		90	90	90	90	90	75-90
Feed Cushion (inches)		½	½	½	½	⅛, 1	½

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Electro-Thermal Analysis of Thermosetting Polymers

This process may lead to a greater understanding of the mechanism of degradation of complex polymers. In particular, it may be possible to calculate the activation energy of degradation

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The use of thermosetting polymers, often under conditions of high temperature is rapidly increasing; but information on their thermal stability is very limited. A few investigations employing the techniques of Differential Thermal Analysis (DTA) and Thermo-Gravimetric Analysis (TGA) have been made, but the total number of polymers investigated is very small. These two experimental techniques, while very useful in elucidating the kinetics and mechanism(s) of the thermal degradation of crosslinked polymers, yield very limited information on their structure and other characteristics during degradation. Also, both techniques require specially prepared samples and are not suited to yield information on the degradation characteristics of bulk polymers.

Electrical resistivity techniques have not been previously employed to study the stability and degradation of bulk thermosetting polymers. However, several limited applications of resistivity techniques have been reported in which the structure of carbon (1) and several pyrolysates (2) were studied. These techniques have been previously employed to study the rate and extent of polymerization (3), the nature of the electrical conduction process (4), and the temperature dependence of the electrical resistivity (4, 5) of both thermosetting and thermoplastic polymers. Resistivity techniques are also employed to study the structure and properties of organic semiconductors (6). In previous work it has been shown that the magnitude and temperature dependence of the resistivity of a polymer exhibit their maximum values when the extent of polymerization is at a maximum (4). It was also noted that excessive attempts to polymerize a sample at elevated temperatures resulted in decreases in these parameters. Speculation as to the significance of this decrease prompted the investigation reported here. Thermal degradation studies of several selected polymers have now been made by electrical resistivity techniques and it has been found that data can be obtained on the onset, rate, and extent of degradation of bulk thermosetting polymers. This new technique, termed Electro-Thermal Analysis (ETA), has been employed to study the thermal stability and degradation of three typical crosslinked polymers in order to illustrate typical data which may be obtained.

BEST OF ANTEC!

Theoretical

A completely polymerized sample of polymer will exhibit maximum values of the magnitude and temperature dependence of the electrical resistivity. Upon pyrolysis these parameters will undergo a progressive decrease: the magnitude of the resistivity will approach that of carbon, i.e., about 10^2 to 10^3 ohm-cm, while the temperature dependence will approach the flat or zero dependence which is characteristic of carbon. Electrical conduction in organic polymers is predominately ionic in nature (4), while conduction in carbon is electronic (7) and, for the most part, independent of temperature. As pyrolysis proceeds, the amount of carbon in the pyrolysate increases as the organic portions of the polymer are burned off. Pinnick (1) has pointed out that as the temperature of pyrolysis is increased, the amount of a highly crosslinked carbonaceous residue consisting of condensed rings of a benzene type is increased.

The results obtained in the present study indicate that during pyrolysis an organic polymer is progressively converted into a dense, rigid, carbon-carbon primary bond network. This network is extensively conjugated, as is evidenced by the magnitude and temperature dependence of the resistivity. It has been previously shown by Akamatu and Inokuchi (6) that continuous, conjugated chains appear to be fairly good electrical conductors and that conjugated systems would be expected to exhibit the magnitude and temperature dependence which has been observed for these residues. The low activation energy of the electrical conduction process found for many of the pyrolysates is additional evidence for the existence of electronic conduction in a conjugated, condensed, ring network. These considerations form the basis for using resistivity measurements to investigate the degradation of crosslinked polymers.

Apparatus and Experimental Technique

The continuous current monitoring device (CCMD), which is a simple application of Ohm's law, was used to determine the electrical volume resistivity of the polymers before, and after, pyrolysis. This device consists of a Keithley Model 210 electrometer, Keithley Model 2008 decade shunt, and a cell which consists of two brass, parallel plate electrodes separated by two small spacers made of either polytetrafluoroethylene or glass. The parallel plate electrodes of the CCMD were completely encapsulated by the polymer. This instrument is required to monitor the change in resistivity (10^6 to 10^{16} ohm-cm) which occurs within a polymer as a function of temperature or a result of degradation. All values of the resistivity reported here were made at a field strength of about 225 volts/cm. Pyrolysis was conducted in a small oven. The temperature dependence of the resistivity before and after pyrolysis was determined by monitoring the resistivity of the polymer as the sample was slowly cooled. The electrodes and the experimental arrangement employed to measure the electrical volume resistivity continuously have been previously described (8). These measurements lend themselves to automation.

Materials

The materials considered in this study consisted of three commercially available thermosetting polymers. These polymers were chosen as being representative of the polymers currently employed in high temperature applications. The first was an epoxylated-novolac, D.E.N. 438, which is made by the Dow Chemical Corporation. It can be represented by the general formula:

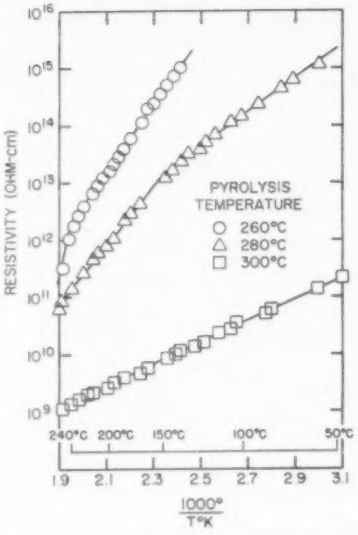
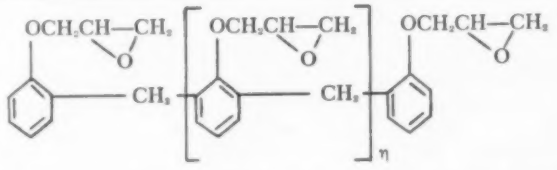


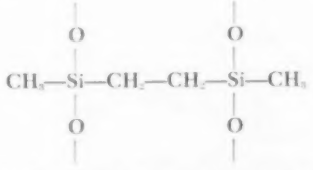
Figure 1. Temperature dependence of the electrical resistivity of Dow D.E.N. 438 after pyrolysis for 16 hours at various temperatures



where η is equal to about 1.5. This polymer, which was polymerized with 100% by weight of methyl nadic anhydride, polymerizes through the epoxide groups. The manufacturer describes it as being thermally stable at 260°C.

Stycast TPM-4, manufactured by Emerson and Cuming Company, was the next material considered. This is a fluorinated hydrocarbon polymer intended for high temperature applications.

The final polymer considered was RTV-60, a silicone elastomer, made by the General Electric Corporation. This material consists of methyl and phenyl groups attached to silicon atoms in a silicon-oxygen chain (9) and was polymerized by 1% of dibutyl tin dilaurate. McGregor (10) gives the following structure for a crosslinked silicone where some of the methyl groups may be replaced by phenyl groups:



Madorsky (11) has found that polymers of this type yield large amounts of benzene when pyrolyzed.

Results and Discussion

The results of this investigation are shown in *Figures 1, 2* and *3* which are semilogarithmic (Arrhenius) plots of the resistivity vs temperature for the polymers after pyrolysis for 16 hours at various temperatures. In each case the pyrolysis temperature is noted on the figure. The activation energy for the electrical conduction process, E_c, can be calculated from the slopes of the plots (4, 5).

The ETA results with D.E.N. 438 are shown in *Figure 1*. This polymer appears to be thermally stable up to 260°C

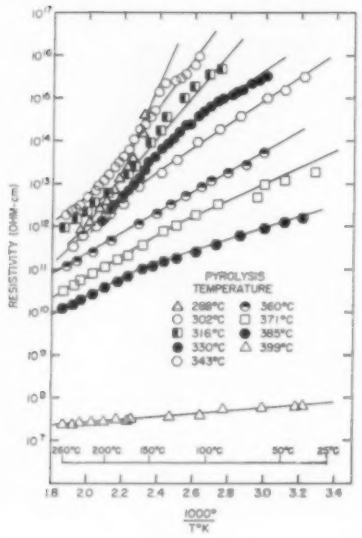


Figure 2. Temperature dependence of the electrical resistivity of Stycast TPM-4 after pyrolysis for 16 hours at various temperatures

since the maximum magnitude and temperature dependence are found after heating at this temperature. Above 260°C degradation occurs, as evidenced by the decrease in both the magnitude and temperature dependence of the resistivity. After the pyrolysis at 371°C the polymer crumbled and additional measurements were not possible. However, the expected progressive decrease in the two electrical parameters was observed. It is of interest to note that the change in the slope of the resistivity vs temperature plot for completely polymerized D.E.N. 438 indicates that a glass transition occurs at about 240°C (12).

The Stycast TPM-4 results are shown on *Figure 2*. This material exhibits maximum values for both the magnitude and temperature dependence of the resistivity after pyrolysis at 288°C. However, once these maxima are attained, additional pyrolysis at temperatures greater than 288°C results in a progressive decrease in both the magnitude and temperature dependence of the resistivity. For example, pyrolysis at 302°C results in the onset of degradation. After pyrolysis at 385°C, an increase of only 14°C to 399°C results in a major change in both the magnitude and temperature dependence of the resistivity. It appears that an abrupt increase in the rate of carbon formation occurs between these two temperatures. The resistivity magnitude approaches the semiconductor range of 10^7 ohm-cm and the temperature dependence is close to that of carbon. This abrupt change in these two parameters suggests that above 385°C the last remaining portions of organic polymer are burned off and a residue is produced which is essentially a form of carbon. Also, it appears that this carbonaceous residue is a semiconductor. This pyrolytic method for the preparation of semiconductors is outwardly similar to that employed by Pohl and co-workers (13).

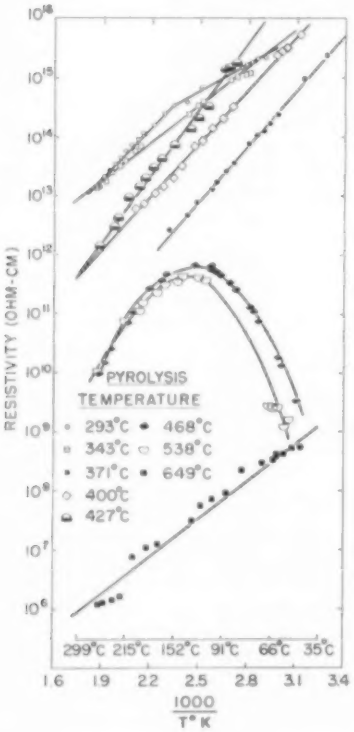


Figure 3. Temperature dependence of the electrical resistivity of a silicone polymer after extensive pyrolysis

The apparent success of the ETA technique with conventional organic thermosetting polymers prompted the study of a typical silicone polymer. The results of this study are shown in *Figure 3*. A generally similar behavior was observed in the early stages of pyrolysis. However, a significant departure from the usual results was obtained in the later stages of the degradation. After pyrolysis at 468°C the resistivity, instead of exhibiting the usual linear dependence, changed slope and direction of its plot vs temperature. The plots obtained after pyrolysis at 468°C and 538°C approximate a parabola. This is very unusual and has not been previously observed with other polymers. These parabolic plots are reproducible and can be obtained on other samples of the same polymer after four successive pyrolyses over the temperature range 460°C to 595°C (14). Attempts to explain this phenomenon have been unsuccessful. However, it appears possible that some basic change occurs in the structure and/or the electrical conduction mechanism of the pyrolysate over this temperature range. Once the temperature range is exceeded, the temperature dependence becomes normal as is indicated by the results obtained after pyrolysis at 649°C. The final product obtained after the degradation of a silicone polymer is a siliceous residue which would be expected to exhibit the electrical properties of SiO_2. This data on the thermal stability of silicone polymers agrees with that of Madorsky (11) who also found that these materials exhibit good thermal stability. Lewis (15) has concluded that the thermal degradation of silicones is extremely sensitive to minute traces of impurities.

It should be noted that the time of pyrolysis (16 hours) was arbitrarily chosen. Longer pyrolysis time at lower or higher temperatures would be expected to yield somewhat different results.

Conclusions

The results presented here indicate the types of data and conclusions which may be drawn from ETA investigations on thermosetting polymers. However, it is also expected that other types of data should be obtainable. For example no data have been presented on the isothermal degradation of thermosetting polymers. This phase of the ETA technique, in which the changes in the resistivity during isothermal degradation are continuously monitored, should yield data indicative of the kinetics of the degradation process. In particular, from a series of isothermal degradations, it should be possible to calculate the activation energy for the degradation process. Such information might be a major contribution toward the understanding of the mechanism of the degradation of these complex polymers.

Recently, Morton and co-workers (16) have shown the usefulness of this technique in studying the isothermal degradation of a polyurethane polymer at 157°C. The resistivity technique employed was based on that presented in reference (8).

Recent work at the Naval Ordnance Laboratory has shown that polyamide-epoxide and polyurethane polymers can be degraded isothermally and the rate of degradation determined by resistivity measurements.

Recently Bassin (17) has found that these ETA techniques are useful in studying the degradation of propellant binders and solid propellants. This work resulted from a suggestion made by the Naval Ordnance Laboratory (18).

A significant point is that the data presented here are very useful. For example, it has previously been shown (8, 12) that a large number of the most important electrical properties of a polymer can be determined by the CCMD on a single sample. The same sample can also be used for the ETA study. Thus, a complete profile of the electrical properties of the bulk polymer can be obtained before, during, and after polymerization by means of the experimental techniques presented here and in previous (8, 12) papers.

These determinations are simple to make, rapid, require a minimum of complex instrumentation, and can be conducted by a technician. It is suggested that this technique could be standardized as a test method for thermal stability determinations. Madorsky and Straus (19) have recently suggested that the thermal stability of a polymer can be defined as the tendency to yield a carbonaceous residue and that the amount of carbon in the residue could serve as a measure of the thermal stability. ETA is not restricted to any particular type of thermosetting polymer and can be used on filled and laminated plastics and on elastomers. The use of this technique in the preparation and study of organic semiconductors is also of interest.

Acknowledgment

The author would like to express his appreciation to Mr. G. D. Blum and Mr. Thomas Wade for assistance in the experimental part of this work.

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Heating Capacity Limitations of Extruder Screws

B. H. Maddock
Union Carbide Plastics Company
Division of Union Carbide Plastics Company

Extrusion coating of paper or other substrates poses the problem of achieving and maintaining high stock temperatures

The ultimate output capacity of the single screw extruder is a function of many variables, including the available drive power, maximum screw speed, barrel heater capacity and heat transfer area, and screw geometry. In addition to machine design and operating variables, the thermal conductivity, melt viscosity, thermal stability and other properties of the plastic material must also be considered. The problems encountered in achieving high stock temperatures for applications such as extrusion coating of paper or other substrates will be weighed. While the experimental data covers only low-density polyethylene, the principles involved and many of the conclusions drawn apply equally well to other types of polymers.

Table 1. 2.5-in. Extruder

L/D Ratio (total threaded length)	23.6/1
Barrel Heater Capacity	28.8 KW
No. of Heating Zones	5
Drive Motor (Dynamatic)	50 HP
Maximum Screw Speed	280 RPM

Experimental Equipment

This work was carried out in a 2.5-in. diameter extruder having the characteristics shown in *Table 1*.

Two screw designs were studied. *Screw A* was a conventional, "polyethylene" type having a 4-turn metering section with a channel depth of 0.094-in. *Screw B* had a 13-turn metering section with a channel depth of 0.110-in. These screws are further defined in *Table* 2.

Heating Mechanisms

Most extruders are operated with cold feed—that is, with plastic pellets or powders fed to the machine at room temperature. Heat is introduced into the plastic both by conduction from the heated barrel and by frictional work-

BEST OF ANTEC!

Bruce H. Maddock *was graduated from the University of Michigan in 1934 with a B.S. degree in Engineering Physics. In 1935 he joined the Union Carbide Plastics Company, and participated in the development of electrical insulation materials and extrusion processes for wire insulation. From 1942 to 1945 he served as chief engineer of the Intelin Division, Federal Telephone and Radio Corporation, then returned to Union Carbide Plastics Company for further work in extrusion materials. Mr. Maddock is well known throughout the extrusion industry for his numerous papers on fundamentals of extrusion, many of which have been presented before technical conferences.*

Table 2. Screw Designs

	Screw A	Screw B
Total threaded length, inches	59	59
Feed section, length, inches	7.5	7.5
Feed section, depth, inches	0.450	0.450
Transition section, length, inches	41.5	19
Transition section, depth, inches	continuously	decreasing
Metering section, length, inches	10	32.5
Metering section, depth, inches	0.094	0.110
Lead, inches	2.5	2.5

ing between the barrel and the rotating screw. The amount of heat introduced by each method depends upon the screw design and speed, the melt viscosity characteristics of the plastic material and the barrel temperature. A certain amount of heat is generated automatically by frictional working. The additional heat necessary to bring the material to the desired temperature occurs by transfer from the heated barrel and is controlled by the zone temperature controllers on the barrel heating system.

In practice, the mechanisms are not quite so simple. Conductive heating predominates in the rear section of the machine where the screw channel depth is the greatest, the material is not yet melted and conditions, in general, are not favorable for frictional heat development. As the pellets become warmed by conducted heat and packed into the transition area, frictional working comes into play and gradually assumes a more prominent role. In the forward end, or metering section, frictional heating usually predominates due to the smaller channel depth and greater rate of shear. In some instances, excessive frictional working may cause the stock temperature to rise above the desired level, necessitating some form of cooling to remove the unwanted heat.

Energy Relations

The energy required to raise the material temperature is given by:

$$Z = QC\Delta T \qquad (1)\ (1, 2)$$

where Z = power, in.-lbs./sec.
Q = volumetric rate of heating (extrusion), in.^{3}/sec.
C = Specific heat of plastic, in.-lbs./in.^{3}-°C.
ΔT = Temperature rise, °C.

If this energy is generated by frictional working, the following relation applies:

$$Z = Q\eta\gamma \qquad (2)$$

where η = melt viscosity of plastic, lb.-sec./in.^{2}

γ = rate of shear, sec.$^{-1}$

Equating (1) and (2), the temperature rise due to frictional working is related to the product of the material viscosity and the rate of shear:

$$\Delta T = \frac{\eta\gamma}{C} \qquad (3)$$

The shear rate at a particular point in the screw channel is given by:

$$\gamma = \frac{\pi DN}{h} \qquad (4)$$

where D = barrel diameter, inches
N = screw speed, rps
h = channel depth, inches

The temperature rise due to frictional working for a given diameter extruder is thus a function of the screw speed, material viscosity and channel depth:

$$\Delta T = \frac{\pi DN\eta}{Ch} \qquad (5)$$

Equation (5) is not as simple as it might appear, however, since the viscosity of most polymeric materials decreases both with increasing rate of shear and with increasing temperature in complex manners. The mathematics of these mechanisms has been developed by McKelvey and Bernhardt (1). Equation (5) does illustrate that under conditions where a major portion of the energy input to the material is by frictional working, a rise in temperature would be expected with any increase in screw speed or decrease in channel depth. Experience has confirmed these effects.

Low Temperature Applications

Polyethylene extruded products, such as pipe, blown tubular film, heavy sheeting and some contour sections, require a relatively low extrudate temperature of 150-200°C. (302-392°F.) for reasons of cooling or mechanical handling. Low barrel temperatures are normally employed

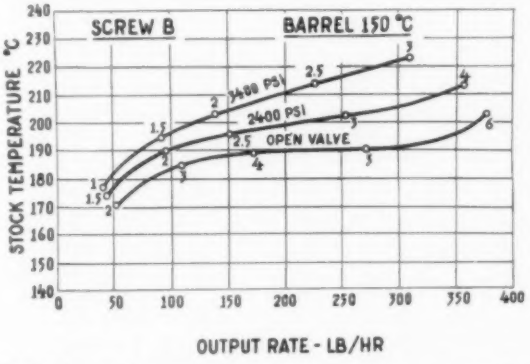

Figure 1. Stock temperature vs output rate Screw B—150°C

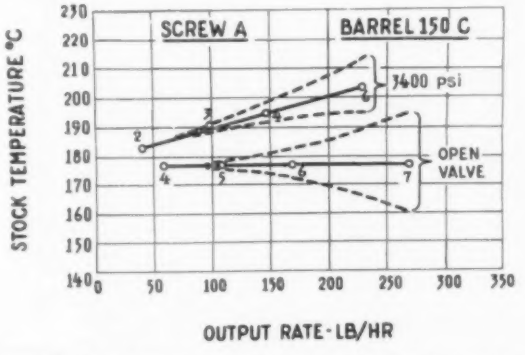

Figure 2. Stock temperature vs output rate Screw A—150°C

in these applications. Under such conditions, with a screw designed for adequate mixing, frictional heating does predominate and the stock temperature rises with increasing screw speed and output rate. The factor limiting the output rate may then be the ability to keep the temperature down to the desired level and barrel cooling may be required to assist in this function.

Stock temperature is plotted against output rate in *Figure 1* for screw B at a uniform barrel temperature of 150°C. A blend of 0.918 density, 2.0 melt index, natural polyethylene pellets with about 5% of red pigmented pellets of the same base resin was extruded through a pressure control valve and a 3/16-in. diameter rod die. Readings were taken at 40, 80, 120, 200 and 280 rpm and at three head pressures—open valve (approximately 1000 psi), 2400 and 3400 psi. Quality of mixing was evaluated by pressing the extruded rods into sheets of 0.030-in. thickness and examining them for color streaks and uniformity of background. An arbitrary quality scale was used where *number 1* represented an excellent color dispersion and smooth extruded rod surface and *number 7* was very poor in both respects. A quality of 3 was considered a minimum level of commercial acceptance. The numbers along the curves of *Figure 1* are the quality ratings at each point.

Stock temperatures were measured by an immersion type thermocouple in the plastic stream near the tip of the screw and recorded on a strip chart recorder. The fact that the readings were well above the barrel settings of 150°C. indicates that the operation was essentially adiabatic under these conditions, at least in the forward end of the machine. The stock temperature rises with increasing screw speed and output rate due to the increase in rate of shear. Raising the head pressure by closing the valve increases the rate of frictional heat development, causing earlier fluxing and a more rapid rise in temperature with increasing output rate.

Mixing quality, in general, becomes worse as the output rate is increased at any pressure condition, but an acceptable quality level of *grade 3* was maintained at 280 rpm and 3400 psi with an output rate in excess of 300 lb./hr. Still better mixing could have been achieved at all speeds by increasing the pressure still further and by this means it would have been possible to go to still higher speeds and output rates. The stock temperature would also have been higher, however.

Screw B, because of its extra long (13-turn) metering section and correspondingly high residence time under conditions of optimum shear, gives good quality at output rates considerably greater than ordinarily considered possible from a 2.5-in. extruder. Substantial frictional heating occurs at low barrel temperatures, however, and it would not be possible to achieve these high rates at stock temperatures below 200°C. with 2.0 melt index material, except by use of external cooling. Lower melt index (higher molecular weight) resins would give even higher stock temperatures.

Results with the more conventional type screw, A, are shown in *Figure 2*. Only the data for the open valve and 3400 psi conditions are plotted and the screw speed was not increased above 200 rpm due to the extremely poor quality obtained at that speed. Wide and rapid temperature fluctuations were also recorded at the higher screw speeds. The dotted lines indicate the ranges of observed temperature. In comparison, the maximum variation in stock temperature with *screw B* was ± 1°C.

Quality ratings with *screw A* are considerably poorer and the temperature levels slightly lower than those obtained with the long metering section *screw B*. Acceptable quality was not reached with *screw A* at rates above approximately 100 lbs./hr. and even then only at the higher head pressure of 3400 psi. The poorer mixing with *screw A* is attributed to the shorter residence time in the metering section which over-weighs the fact that the metering section channel depth (0.094-in.) was less than that of *screw B* (0.110-in).

High Temperature Applications

Applications requiring higher stock temperatures include extrusion coating and, in some cases, flat film and wire coating. At low barrel temperatures it has been noted that with screws which give suitable mixing and product quality, frictional heating predominates, leading to adiabatic operation, overriding of barrel temperature settings, increasing stock temperature with increasing screw speed and a generally high drive power requirement. To achieve still higher stock temperatures for applications such as paper coating, it is necessary to introduce additional conducted heat. As the barrel temperatures are raised, a point is eventually reached where the operation becomes conducted-heat-dependent, and the material temperature decreases with increasing throughput due to a limitation in heat transfer capacity.

Operation of *screw B* at barrel temperatures of 250°C. (482°F.) and 350°C. (662°F.) is illustrated in *Figure 3*. At 250°C. open valve, the stock temperature decreases continuously with increasing screw speed and output rate. Frictional heat generation has been reduced as a result of the higher barrel temperature (compared to 150°C.) and heat transfer from the barrel determines the extrudate temperature. The temperature drops with increasing throughput due to the reduction in residence time. Raising the head pressure increased the frictional heat development and the stock temperature.

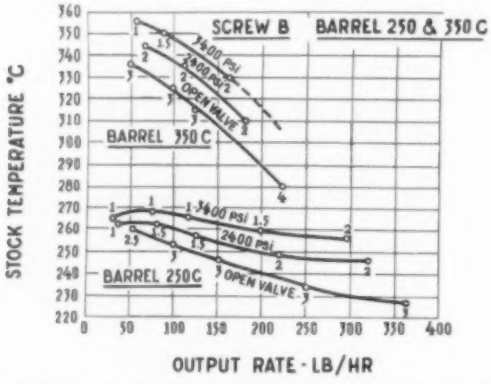

Figure 3. Stock temperature vs output rate Screw B—250° and 350°C

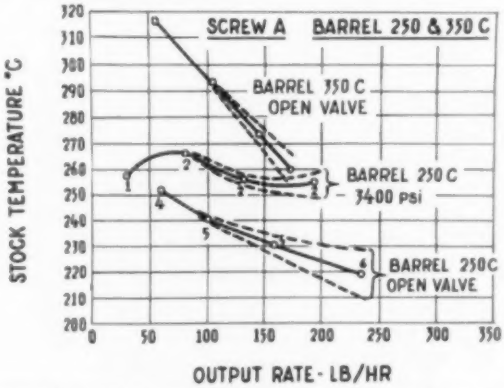

Figure 4. Stock temperature vs output rate Screw A—250° and 350°C

Comparing *Figure 3* with *Figure 1*, it is seen that quality is better at the higher barrel and stock temperatures and that the quality is affected less as the output rate is increased. This appears to be a result of earlier melting and fluxing in the screw and a longer resultant time of mixing in the molten state, rather than any primary effect of temperature or viscosity.

At a uniform barrel temperature of 350°C., *Figure 3*, the operation is conducted-heat-dependent at all three pressures and the temperature decreases continuously with increasing output.

With this long metering section screw it would be possible to attain at least 400 lbs./hr. of good quality product at a stock temperature of 250°C. (482°F.) or 250 lbs./hr. at 300°C. (572°F.). By increasing the head pressure still further it should also be possible to obtain 250 lbs./hr. at 330°C. (626°F.). These rates are considerably higher than normally experienced with 2.5-in. machines. The maximum output rate obtainable in coating applications is usually determined by the ability to maintain the necessary temperature.

Results with *screw A* at the higher barrel temperatures are shown in *Figure 4*. This screw is even more dependent upon conducted heat and does not give satisfactory quality except at high pressures. Fluctuations in stock temperature were again observed at the higher output rates. Quality evaluations and elevated pressure runs were not made at the 350°C. barrel temperature conditions.

Drive Power Requirements

Power delivered to the screw is plotted against output rate in *Figure 5* for the open valve condition. Essentially identical curves were obtained with both screws. The quality levels were quite different, however, indicating that the improvement in quality with *screw B* was obtained at no expense in drive power. All of the curves were slightly higher at elevated head pressures.

The reduced power requirement at the higher barrel temperatures reflects the increase in conducted heat input under those conditions.

Mechanical work (HP-hr./lb.) is obtained by dividing the power by the extrusion rate. The ratio of this factor (mechanical work) to the heat content or enthalpy of polyethylene at the extrusion temperature (x100) gives the per cent mechanical heat or the proportion of the heat introduced by frictional working.

Per cent mechanical heat is plotted against output rate in *Figure 6* for *screw B* at the open valve condition. At the low barrel temperature of 150°C., most of the energy input was by frictional working as previously concluded from the stock temperature curves of *Figure 1*. Frictional heat increased with increasing screw speed as predicted from Equation (5). As the barrel temperature was raised and more heat introduced by conduction, the drive power and frictional heat were lowered because of the reduction in melt viscosity in the screw channel. At 350°C. barrel temperature, only 20 to 50 per cent of the necessary heat was put in by frictional working. The balance of the necessary heat must be introduced by transfer from the heated barrel. Therefore, the maximum output rate at a given stock temperature is actually determined by the heat transfer rate, a function of barrel temperature. These curves were also raised slightly at higher pressures.

Extrusion economy (lb.HP-hr.) is the reciprocal of mechanical work. This is plotted against output rate in *Figure 7* for *screw B*, open valve. Higher values are noted at the higher barrel temperatures and lower output rates due, again, to the lower order of frictional heat development under those conditions. As the adiabatic state is approached at high screw speeds and output rates, the extrusion economy values drop to the range of 9 to 11 lb./HP-hr.; this corresponds, roughly, to the energy required for heating polyethylene to the extrusion temperature. Raising the head pressure lowers the economy curves slightly due to increased frictional working.

Effect of Resin Viscosity

Increasing the resin molecular weight and melt viscosity results in increased frictional heat development and higher stock temperatures at any set of operating conditions. This would be expected from equations (3) and (5) and is illustrated in *Figure 8* for 0.92 density polyethylenes of 7.0, 2.0 and 0.1 melt index. The difference in melt viscosity between resins of 7.0 and 2.0 melt index is not great compared to the change in going from 2.0 to 0.1 melt index. The 0.1 melt index material gave essentially adiabatic operation at a barrel temperature of 250°C., similar to the

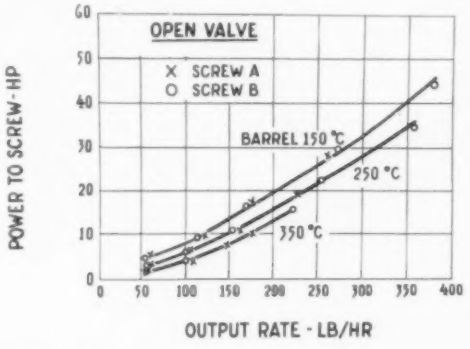

Figure 5. Drive power vs output rate

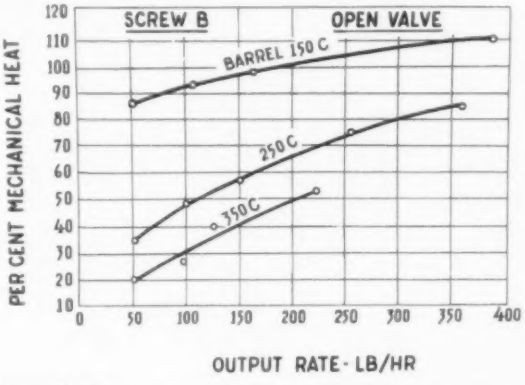

Figure 6. Per cent mechanical heat vs output rate

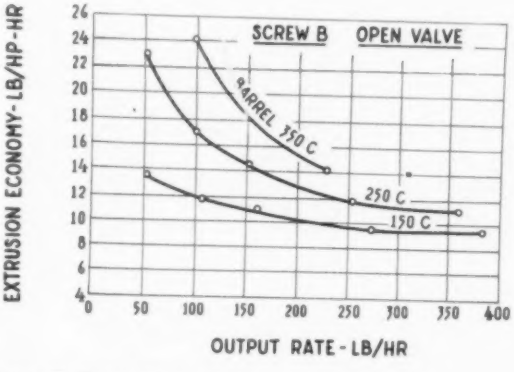

Figure 7. Extrusion economy vs output rate

results with the 2.0 melt index material at the lower barrel temperature of 150°C. (*Figure 1*). Increasing the head pressure again raises all of the curves of *Figure 8*.

High stock temperatures could be achieved more easily with the lower melt index (higher molecular weight) resins because of the increased frictional heat generation under any condition of shear. However, most resins used for extrusion coating applications are of the lower molecular weight type with melt indices in the range of 4 to 8. These resins are used to achieve maximum penetration of and adhesion to the paper or other carrier medium. Even with the greater fluidity of such materials, stock temperatures of 320°C. (608°F.) or higher are ordinarily required. At barrel temperatures necessary to produce stock temperatures in this range, it has been shown that frictional heat

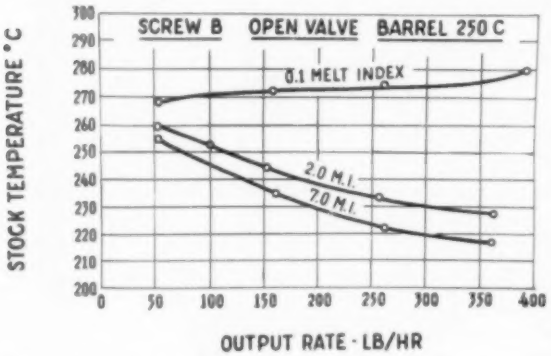

Figure 8. Effect of melt viscosity on stock temperature

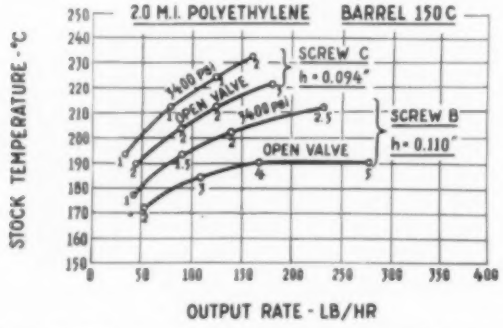

Figure 9. Effect of channel depth on stock temperature

generation is likely to be low and the process dependent largely upon conducted heat.

Effect of Metering Section Channel Depth

A further method of increasing frictional heat generation, and thereby the stock temperature, is to reduce the channel depth in the metering section and then run at a higher screw speed to regain the loss in output rate. Both of these changes cause increases in shear rate (equation 4) and stock temperature (equation 5). The residence time in the metering section is reduced in proportion to the increase in screw speed and the total shear (product of shear rate and residence time) is increased in proportion to the reduction in channel depth. The increase in total shear causes improvements in mixing at a given output rate.

These effects are illustrated in *Figure 9*. *Screw C* was identical to *screw B* except that the metering section channel depth was reduced to 0.094-in. This screw gave 20° to 30°C. higher stock temperature and better quality at a given output rate, either at the open valve or 3400 psi pressure conditions.

Conclusions

One of the main factors determining the output capacity of extruders in applications requiring high stock temperatures is the ability of the system to maintain the desired temperature. Since the process is essentially conducted-heat-dependent, the barrel surface area and barrel heater capacity are limiting factors. Maximum barrel surface is obtained by use of high length to diameter ratios, 24 to 1 or greater being most desirable.

The high L/D ratio is most effectively used if a major portion of the screw length is devoted to a shallow channel metering section. This gives conditions favorable for heat transfer, but also provides greater frictional heat development, better mixing and a more uniform melt temperature than possible with screws having short metering sections. A minimum metering length of 50% of the total screw length is recommended, although even longer metering sections have been successfully employed.

The resistance of extrusion coating dies is ordinarily low due to the low viscosity of the resin at the high extrusion temperature. This results in a relatively low head pressure, usually under 1500 psi. Raising the head pressure by means of a valve between the screw and the die increases the amount of frictional heat. This is added to the conducted heat, permitting maintenance of the desired stock temperature at higher screw speeds and output rates. The use of a valve for this purpose is strongly recommended.

Literature References

1. McKelvey, J. M. and Bernhardt, E. C., "Adiabatic Extrusion of Polyethylene", *SPE Journal 31*, March, 1954.
2. Maddock, B. H., "Power and Heat Energy Relations in Polyethylene Extrusion", SPE 14th ANTEC, January, 1958. Also Union Carbide Plastics Company, *Kabel-items No. 105*, March, 1958.

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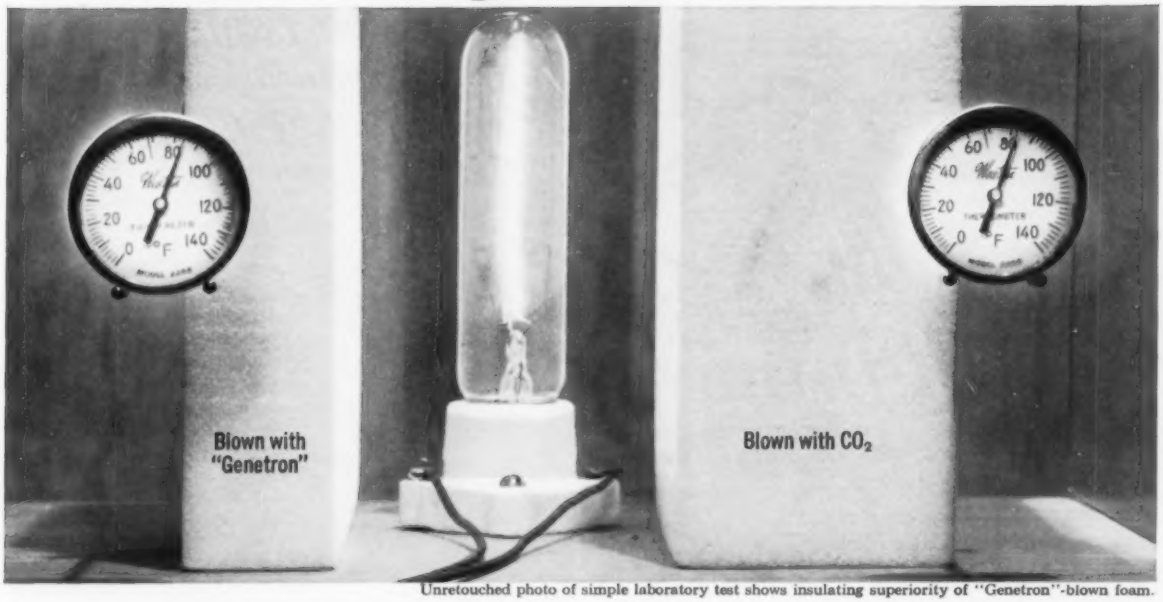
AMERICAN PLASTICS INSTITUTE TO BE LAUNCHED THIS YEAR

The Plastics Institute Committee of SPE has decided to proceed with formal incorporation of the Plastics Institute of America as a non-profit organization. Jules W. Lindau, III, is the newly-elected chairman of the Committee. The Committee has been working out detailed plans for such an Institute for the past four years. The projected Plastics Institute will seek to fulfill the need for basic, fundamental research into the properties and characteristics of plastic materials and other significant aspects of the science and engineering of plastics, and will disseminate the findings of the research to all levels of plastics production, processing, and end-use.

Professor Louis F. Rahm, director of the Plastics Laboratory at Princeton University, and chairman of the Committee during the past year, presided at the meetings held in Washington, D. C. this past January. Other members of the Committee who will continue to serve until the formal incorporation is effected; Mr. Jerome Formo, A. A. Hutchings, vice-president of F. J. Stokes Corporation, Philadelphia; Ralph L. Mondano, until recently manager of the plastics plant of Raytheon Company, Maynard, Mass.; and George Smoluk, engineering editor of MODERN PLASTICS magazine. Newly appointed members of the Committee are: S. E. Q. Ashley, manager of General Electric Company's Major Appliance Laboratories, Louisville, Kentucky, Emil Ott, formerly vice-president in charge of research and development for the Chemical Divisions of Food Machinery and Chemical Corporation and now a member of the staff of Rutgers University, New Brunswick, N. J.; and Dr. Frank Reinhart, chief of the Plastics Section of the National Bureau of Standards, Washington, D. C.

Half the "k"-factor of ordinary urethane!



Unretouched photo of simple laboratory test shows insulating superiority of "Genetron"-blown foam.

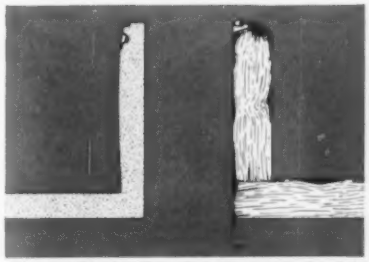
Insulation of genetron®-blown foam is up to twice as effective as carbon dioxide-blown foam... more than 2 times as effective as glass wool batting.

Now there's a new and better way to make urethane foams for thinner wall insulation . . . with "Genetron" blowing agents. "Genetron"-blown foams offer far superior insulating performance—as much as 2 times the insulating value of CO_2-blown foam and 2½ times that of glass wool batting. With "Genetron"-blown urethane, storage capacity of refrigerators and freezers can be increased on the order of 20% without increasing outside dimensions.

"Genetron"-blown foams offer many important working advantages, too. They rise at lower temperatures, permitting larger forms to be prepared. They are easier to control, because "Genetron" does not react chemically with other constituents. They cure rapidly, even at room temperature. They are safer... release less of the toxic vapors and no flammable vapors.

In addition, when foamed in place, "Genetron"-blown urethanes provide all the structural advantages of ordinary urethanes . . . stronger construction . . . better support for deep cavity liners.

For further information write for General Chemical's comprehensive technical bulletins, "Genetron Blowing Agents for Rigid Urethane Foam," and "Determining Genetron Content of Rigid Urethane Foam."



Cutaway drawing shows how the superior insulating properties of foamed-in-place "Genetron"-blown urethane foams save space in refrigerators, freezer boxes and other applications. Storage capacity can be increased on the order of 20% without increasing outside dimensions.

Other major components of the urethane foam system are also produced by Allied Chemical. These components are: Nacconate® diisocyanates by National Aniline Division; polyester resins by Plastics and Coal Chemicals Division.

Allied Chemical

GENERAL CHEMICAL DIVISION
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***Translation: For low temperature applications, depend on Pittsburgh ADIPATE Plasticizers.** Pittsburgh Adipates are available as esters of n-octyl n-decyl, 2-ethylhexyl, iso-decyl and iso-octyl alcohols . . . designed to meet your exacting low temperature flexibility requirements. *Whatever* your plasticizer needs, call on Pittsburgh Chemical, a company that takes pride in its ability to provide uniform, high purity products . . . delivered on schedule . . . backed with competent technical "know-how." 2749

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PAG Progress

George Lubin, *1960 Chairman, Reinforced Plastics PAG (Grumman Aircraft Engineering Corporation)*

and

Herbert E. Ennis, *1961 Chairman, Reinforced Plastics PAG (The Brunswick, Balke, Collender Co.)*

Broad Program Of Activity Undertaken by Reinforced Plastics PAG

The Reinforced Plastics PAG has recently completed its third year of existence. During 1960 several projects were implemented and at the Group's Annual Business Meeting at ANTEC considerable progress was reported in each of these areas.

A. **PACs**—A committee has actively aided Sections that show interest in reinforced plastics to organize PACs. Assistance has been given by the chairman and committee members in setting up initial meetings and obtaining speakers. During 1960 the North Texas Section organized a Professional Activity Committee on reinforced plastics. This group was aided by copies of previous programs of the New York RPPAG and suggestions on topics and speakers. This PAC is planning a RETEC on a reinforced plastics subject in the near future.

B. **Speakers**—The Speakers Committee, set up to obtain and recommend speakers for ANTEC and to assist local PACs in speaker selection, has developed a list of speakers who had presented papers to the New York Section Reinforced Plastics PAC.

C. **Bibliography**—A committee has prepared a comprehensive bibliography of reinforced plastics literature which was published in the November issue of the SPE Journal.

D. **Engineering Committee**—This committee was formed with the following aims:

1. To evaluate necessity of technical activity in specific fields through subcommittees appointed for particular studies. (The subcommittee members should preferably be working in or have specific interest or knowledge of the subject field).
2. To establish and supervise task groups as recommended and approved by the Group and to define task group objectives.
3. To correlate and collate work and findings of task groups for presentation and discussion at ANTEC and other suitable meetings of SPE.
4. To foster publication of engineering data (i.e., papers, manuals and handbooks).

A task subcommittee of the Engineering Committee prepared a list of high temperature properties desired in evaluation of reinforced plastics.

E. **ANTEC**—A subcommittee assisted the 17th ANTEC Speakers' Chairman in selecting abstracts of papers to be presented at ANTEC and in reviewing final papers and organizing sessions on reinforced plastics. Because so many excellent papers were submitted, the task of selecting the articles was extremely difficult and many very acceptable papers had to be turned down. The ANTEC Speakers' Committee was exceptionally cooperative in their dealings with the PAG.

Officers for 1960 were:

Chairman: George Lubin (Grumman Aircraft Corp).
Vice-Chairman: Walter Stark (H. Stark & Sons)
Secretary: Herbert Ennis (Brunswick, Balke, Collender Co.)

The following Officers were elected at ANTEC for 1961:

Chairman: Herbert Ennis (Brunswick, Balke, Collender Co.)
Vice-Chairman: Harry Raech, Jr. (Food Machinery & Chemical Corp.)
Secretary: Philip Rosenberg (Republic Aviation Corp.)

Major objectives outlined above will be continued in 1961 with particular emphasis on the following:

A. Assistance in organization of new PACs, such as that now being formed by the Eastern New England Section.
B. Coordination of activity of the Engineering Committee to establish design data for reinforced plastics. It was agreed by the Executive Committee to cooperate with a group at Syracuse University in preparation of an engineering handbook on reinforced plastics. It is hoped that comprehensive data can be collected by the Reinforced Plastics PAG and sent to Syracuse for correlation and publication.
C. Preparation by the Engineering Committee of a survey to establish major areas of interest for further work by this Group.
D. Organization of a forum on design data for reinforced plastics to be held at the 18th ANTEC as the major portion of the PAG meeting.
E. Evaluation of possibility of a RETEC in 1962.

Edited by **Saul Gobstein,** *Chairman PAG Executive Committee (Ferro Chemical)*

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The New Standard for PLASTISOLS-ORGANOSOLS

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NEW BOOKS

INTERNATIONAL SYMPOSIUM ON STRESS WAVE PROPAGATION IN MATERIALS

Norman Davids (Interscience Publishers, Inc., 327 pp., $10.00)

Scientists from many diverse disciplines were brought together in a symposium on stress wave propagation by the Office of Ordnance Research in the summer of 1959. The three day conference which was attended by representatives of ten nations, from industry, government, and university laboratories, presented fifteen papers on stress wave studies covering materials such as steel, rocklike matter, viscoelastic solids, and layered solids and liquids. These studies deal with the fundamental properties and structure of matter. Practical applications fall in the field of physical analysis of materials, impact properties, and polymer rheology.

H. Kolsky reviews work on "Viscoelastic Waves" including a summary of the present knowledge in this field plus a discussion on experiments. R. J. Eichelberger outlined fundamental studies on the "Effects of Very Intense Stress Waves in Solids". The evaluations include the effects of stress waves on the electrical conductivity of solids such as lucite, epoxy resins, polyethylene, and teflon, as well as studies on the deformation of single crystals. James R. Kymer outlines the use of polyurethane rubber in fundamental "Experimental Studies in Armor Penetration". Two very basic papers of value to many research fields are K. W. Hillier, "A Review of the Progress in the Measurement of Dynamic Elastic Properties," and E. H. Lee "The Theory of Wave Propagation in Anelastic Materials".

Leo Gans
Anchor Plastic Co.

ABOUT CHEMISTRY

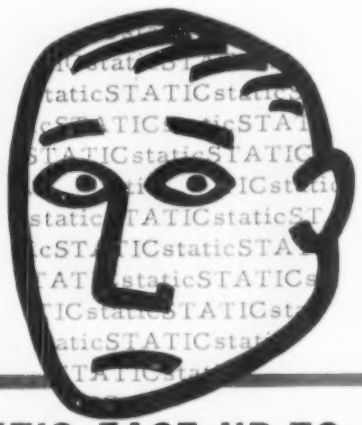
Magnus Pyke (The MacMillan Company, 219 pp., $4.50)

In a condensed form, the author initiates the reader into the field of chemistry and its relations to the other basic sciences. The book is divided into ten chapters. The first ones deal with analysis, composition of matter, chemical reactions, chemistry and metals and catalysts and chemistry. In the second part: carbon chemistry, organic chemistry, biochemistry, plastics and atomic energy.

We have particularly enjoyed reading the chapters on catalysts and chemistry, in which the author describes very clearly chemical phenomena of the greatest importance, and, of course, the one devoted to plastics.

There are 64 illustrations and tables and a very convenient index. Although it is written for the learned layman, this book will be appreciated by many a seasoned chemist.

Dr. Louis C. Barail
Barail Associates



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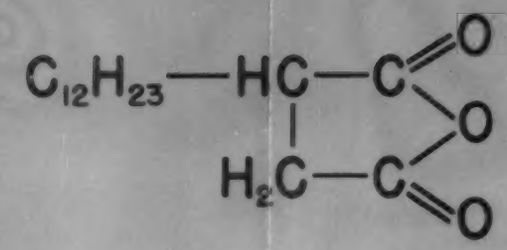
Hidden Potential Developer!



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Subject to further reduction as volume-use grows

We are underwriting increased volume on National Dodecenylsuccinic Anhydride now in the firm belief that it should and will be a major organic.

Why National DDSA?

The well-explored chemistry of this branched-chain alkenyl compound indicates that an economic price is now the only requisite for its widespread use. National Dodecenylsuccinic Anhydride is bifunctional—reacting both as an unsaturated compound and an acid anhydride. With three points for addition reactions, it forms intermediates that lead to unique, improved end-products, such as

Epoxy Curing Agents

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Asphaltic Product Improvers

Fungicides

Surfactants and Wetting Agents and other industrial and consumer products

What National Can Do For You

National has long been the only major custom-producer of Succinic Anhydride and its derivatives. We have recently expanded capacity. We are now prepared to meet foreseeable requirements for National Dodecenylsuccinic Anhydride on an attractive basis.

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If you are or would like to be making any of the products listed (or others outlined in our Technical Bulletin I-8R) ...

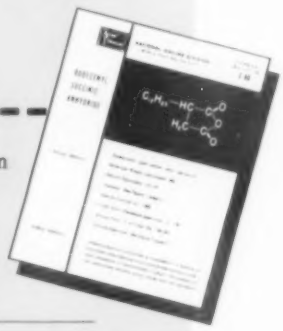
Be sure your Research and Product Development people have the latest data on National DDSA.

Re-evaluate what National DDSA at its new low price can do to expand your product lines, prices and profits.

Let us know your probable requirements so we can work with you for mutual benefit.

Researchers:

Here's 30 pages of data you should have! Technical Bulletin I-8R gives complete physical properties on National DDSA, all important reactions, infrared absorption curve, viscosity curve, and 95 end-use suggestions keyed to a bibliography. Ample working samples will be sent without charge. Use this handy coupon for prompt action.



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So that you can get the information you want in the shortest possible time, we suggest you write directly to the company address listed at the end of each new product item.

New Materials and Equipment

MATERIALS AND APPLICATIONS

Diallyl Phthalate-Based Prototype Stock

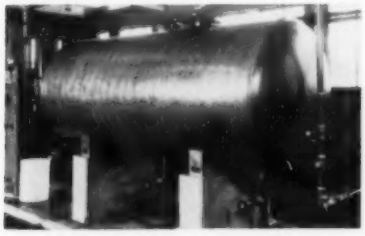
Machining and testing prototypes of plastics parts without the expense of building special dies to mold them is now possible through the use of a stock material from Mesa Plastics Co. Parts and configurations molded of "Diall" (diallyl phthalate resin-based) compounds include panels, slugs, rods, bars, discs, and cylinders in various dimensions. *Dept. SPE,* **Mesa Plastics Co., 12270 Nebraska Ave., Los Angeles 22, Calif.**

New Plasticizer-Stabilizer

A new stabilizing low-temperature plasticizer for PVC, named Monoplex S-74, a monomeric epoxy-ester, has been developed to provide decreased volatility while maintaining good low temperature flexibility and ability. Stabilizes PVC against the effects of heat and light. Contact *Dept. SPE,* **Rohm & Haas Co., Washington Square, Philadelphia 5, Pa.** for technical information.

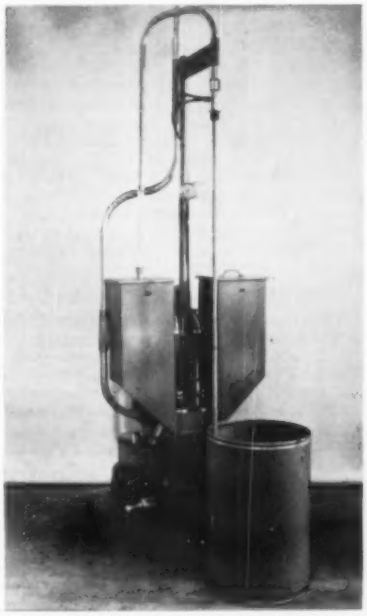
EQUIPMENT

Polyester Used for Corrosive-Resistant Tank



A stock, horizontal 1,000-gallon processing tank, fabricated from a specialty glass-reinforced polyester is available and recommended for such industries as paper, chemical, textile, metals, petroleum, agricultural and others where corrosive conditions demand a structure with high chemical resistance. Tests show that the specialty bisphenol-A polyester resin reinforced with glass fibers is more resistant to prolonged contact with most acids, alkalies and bleaches at high temperatures than general purpose or other polyesters. Information from: *Dept. SPE,* **Justin Enterprises, Inc., 3755 Edwards Rd., Cincinnati 9, Ohio.**

Metering Conveyor



Whitlock Associates, Inc., has introduced a new series 600 Metering Conveyors designed to assist the plastics processor in the use and handling of color concentrate with natural material. Though fully automatic and self-supporting, manual operation is possible so that the proper ratio can be determined by actual weight before the unit is put into production service. Detailed information available, *Dept. SPE,* **Whitlock Associates, Inc., 21655 Coolidge Hwy., Oak Park 37, Mich.**

Variable Speed Drive

Offering dependability in compact space is the new variable speed drive, V*S Statatron, a static powered drive for wide range variable speed from in-plant a-c circuits. Available from 1 to 200 hp, the Statatron uses silicondiodes and saturable reactors to rectify the current from a-c to controllable d-c. Quiet and economical. Write *Dept. SPE,* **Reliance Electric & Engineering Co., 24701 Euclid Ave., Cleveland 17, Ohio** for information.

No Product Contamination

A completely new polyethylene cube net weighing-bagging scale is reputedly designed to minimize the possibility of product contamination while material is weighed. Called E-52, it was created specifically for the plastics materials industry. No dust-collecting ledges or shelves come into contact with material. The scale has exceptional accuracy built into it, ten 100-lb bags per min., with of 2 Sigma 1-oz. For more information, contact *Dept. SPE,* **Richardson Scale Co., Clifton, N. J.**

Dial Rubber Hardness Gauge

Measuring hardness of rubber and other elastomers quickly and easily is a new dial rubber hardness gauge Model 1600, introduced by Rex Gauge Co. Held in a vertical position, the large dial with 360° sweep permits accurate reading to plus or minus ½ Durometer point, consistently and indefinitely.
Durometer "A" scale is used. Details from *Dept. SPE,* **Rex Gauge Co., Inc. Box 46, Glenview, Ill.**

MANUFACTURERS' LITERATURE

Isochem Resins New Hardener Data Sheet

Of interest to epoxy users is the new data sheet listing four new materials. The sheet can be obtained by writing to *Dept. SPE,* **Isochem Resins Co., 221 Oak St., Providence 9, R. I.**

Teflon Information

The care and installation of TEFLON coated equipment is now digested in a new bulletin published by and available through, *Dept. SPE,* **General Plastics Corp., 55 La France Ave., Bloomfield, N. J.**

Tenite Cellulosics Cataloged

A concise description of the properties of Tenite Cellulosic plastics and their application in commercial and industrial products is presented in an 8-page illustrated pamphlet. Dealing with acetate, butyrate and propionate, it summarizes basic characteristics. Write for "Tenite Cellulosic Plastics", *Dept. SPE,* **Eastman Chemical Products, Inc., Kingsport, Tenn.**

U.S.I. POLYETHYLENE NEWS

A series of advertisements for plastics and packaging executives by the makers of PETROTHENE® polyethylene resins

APRIL, 1962

Packaging Notes

Liquid-tight carton with built-in liner of polyethylene-coated paper requires no overwrap. Heat sealing, hot-melt

Wrapless frozen-food carton developed on West coast has polyethylene-coated paper liner which interlocks with flaps on folding. Subsequent heat sealing and gluing complete liquid-, vapor-tight closure.

adhesive and unique design of package all contribute to leak-proof closure. It has proved commercially acceptable for packaging frozen strawberries.

According to the company adopting it, this folding box and special integrated machine which opens, fills and seals it have boosted production speed substantially. Furthermore, it reportedly costs less, is easier to open and provides a better barrier to transmission of water vapor than the metal-end fiber can it has replaced.

Polyethylene squeeze bottles for cosmetics, and toys and Christmas ornaments are now being finished by a new vacuum

metallizing process. Result is an adherent metallic coating—with a texture—which reportedly withstands many squeezings and takes printing without pre-treatment. A choice of colors is available.

According to the developer, process is competitive in cost with ordinary plastics metallizing.

Clams-in-the-shell have joined the growing list of polyethylene-packaged, individually quick-frozen foods. Whole frozen clams are now available on the west coast in 7½" x 13", 3-mil polyethylene bags. According to the marketers, polyethylene was selected for packaging because "it is relatively inexpensive and controls breakage."

DO YOU HAVE a new polyethylene product or development you'd like the industry to know about? Make it routine to send your information on new developments to U.S.I. POLYETHYLENE NEWS.

Address:
U.S.I. POLYETHYLENE NEWS, U. S. Industrial Chemicals Co., Division of National Distillers and Chemical Corp., 99 Park Avenue, New York 16, N. Y.

U.S.I. Announces Plans to Produce Linear Polyethylene

Will Build 60,000,000 Pound-Per-Year Plant at Houston, Texas

U.S.I. will begin construction this Spring on a 60 million pound-per-year linear polyethylene plant at Houston, Texas, adjacent to the company's conventional polyethylene facilities. The new plant, which will mark U.S.I.'s entry into the manufacture of linear polyethylene, is scheduled for completion in the fourth quarter of 1962.

Recently there has been considerable discussion about over-capacity in the linear polyethylene field. Dr. Robert Hulse, general manager of U.S.I., states: "We would not be building this important new plant if we did not believe that over-capacity is a short-term problem and that linear polyethylene is growing in importance. Every market projection we have made indicates that this versatile plastic will be in short supply by early 1963."

PETROTHENE® Trade Name to Be Used

The new U.S.I. plant, designed for easy expansion, will be managed by the same people who are now running the low and medium density polyethylene plant at Houston. The linear polyethylene will be manufactured under a licensing agreement with Phillips Petroleum Company, and will be sold under U.S.I.'s trade name, "PETROTHENE®" polyethylene resin.

Linear polyethylene is stronger and more rigid than the conventional type. It is widely used for blow-molded bottles and containers for industrial products, detergents and other household staples. Other growing markets include injection molded items such as toys and housewares; extruded pipe; and film for heavy duty bags and similar products.

Company Makes Wide Range of Resins

U.S.I. facilities for conventional polyethylene have a rated capacity of 300 million pounds annually. The company currently produces some 100 types of 36 basic low and medium density resins at plants in Houston and Tuscola, Ill. Linear resins are also currently available from U.S.I. pilot plant facilities and through resale arrangements.

New Resins, Equipment Featured By U.S.I. at Packaging Exposition

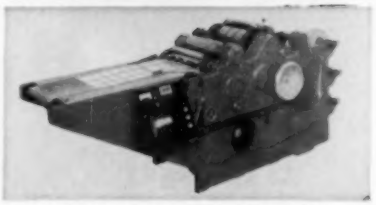
An array of packaging, injection molding and bag-making machines *in action* will be U.S.I.'s main attraction in Booth 1112 at the 30th National Packaging Exposition, April 10-13, at Chicago's Lake Front Exposition Center.

In operation will be three See-Safe packaging machines, which automatically package objects in polyethylene film from slit roll stock. This lineup will include: the Model MA, packaging free give-away items; the MA Jumbo, packaging large products in one step; and the brand new MA-T tilt-top machine, pouring and packaging small parts.

New Bag Making and Injection Molding Machines

Two Conapac machines will also be featured. The "Roto Poly-200", a high-speed heavy-duty machine, will be making bags from blown polyethylene tubing. It has a capacity of up to 200 cycles/min., operates at speeds up to 175 ft./min., and is reportedly the first which can handle *any* density polyethylene film. The "Rotojet" Model T5 will be injection molding small polyethylene containers. Said to be the first rotating turret type machine to appear in this country, it operates at speeds up to 50 shots/min., uses 8 single-cavity molds.

For extruders, converters and packagers of produce, soft goods, hardware or toys, the highlight of U.S.I.'s exhibit will be a new PETROTHENE polyethylene resin. Film extruded from it *combines maximum clarity and gloss with high impact strength, and offers optimum performability as well.* Samples and complete technical data will be available for this and all other PETROTHENE resins.



The See-Safe MA automatic packager (top) and Conapac Roto Poly-200 bag maker are 2 of 5 new machines U.S.I. will feature at the show.

On display, too, will be samples of polyethylene-coated kraft, foil and cellophane. And, a variety of containers—including bottles produced from new PETROTHENE blow-molding resins. Of particular interest will be the 5-gallon collapsible jug just put on the market.

U.S.I. technical representatives will again answer questions and talk over polyethylene packaging innovations. Visitors are urged to use this opportunity to get expert help on specific problems.

ABOUT MEMBERS

Mr. Stansel

Continental-Diamond Fibre Corp. has announced the appointment of **J. C. Stansel** as plant manager. Joining CDF in 1958, Mr. Stansel has served as manager of Process Engineering and most recently as manager of Manufacturing Engineering.

Mr. Perkins

R. B. Perkins has been appointed manager, sales technical service laboratory, Amoco Chemicals Corp., a newly created position. Mr. Perkins joined the company soon after its organization in 1957 and was instrumental in the formation of the sales technical service laboratory which he has headed. A graduate of Rice Institute, '35, Mr. Perkins has been associated with American Oil Co. and Petroleum Rectifying Co.

William M. Reed moves up to President of Plastic Compounding Corp. He has served as Executive VP since 1959, Mr. Reed is a graduate of Ohio State University.

Glenn C. Grimes is now chief engineer of Honeycomb Company of America. He recently resigned as President of Zygo Engineering and Manufacturing. Mr. Grimes is a Registered Professional Engineer, currently working on his M.S. in "aircraft structures."

The newly established district sales office in Detroit opened by the Naugatuck Chemical Division, United States Rubber Co. will be managed by **Robert F. McCabe**, formerly manager of automotive industry sales for the division. The announcement was made by **Harold M. Parsekian,** general sales manager. The "spurting interest" of auto makers in plastics was the reason given for the creation of the new sales office.

J. R. Freyermuth, President, Northwest Plastics, Inc. plays host to Iowa's Governor Norman Erbe, center, as he explains the details of a compression mold at the dedication of the new Plastronics plant in Grudy Center, Iowa. The firm is a wholly owned subsidiary of Northwest Plastics. On hand are, left to right: State Senator Lawrence Putney, E. L. Johnson, Iowa Development Commission, the Governor, Lt. Governor William Mooty and Mr. Freyermuth.

Mr. Matthews

Owens-Corning Fiberglas Corp. has named **Richard A. Matthews** as sales supervisor of Heating and Air Conditioning Products, Sales to Manufacturers Marketing Division. Prior to joining the Fiberglas headquarters in Toledo, Mr. Matthews was a sales representative in the Louisville branch office.

Karl F. Plitt, plastics technologist of the National Bureau of Standards, Washington, D. C., participated in the 46th Annual Meeting of the Technical Association of the Pulp and Paper Industry, reading a paper he wrote with Samuel D. Toner, organic chemist, plastics section. The two wrote papers entitled: "Spectrophotofluorometric Studies of Degraded Cotton Cellulose" and "A study of the Fluorescence of Cellulosic Polymers". Mr. Plitt read the latter.

A Boston Liaison office has been established by Telecomputing Corp. under the management of **Dominick V. Rosato.** Mr. Rosato represents the company in New England, New York, New Jersey and parts of Pennsylvania. The new office will serve the northeast. A graduate of Drexel Institute of Technology, Mr. Rosato was assistant plant manager for Raytheon Co.'s research division before joining Telecomputing. Presently Mr. Rosato is Publicity and Program Chairman of the Eastern New England Section, SPE.

George C. Kiessling has been promoted to the position of technical director, DYLITE expandable Polystyrene in the Product Development Department, Koppers Co., Plastics Division. He is responsible for his department's product development activities.

Continental-Diamond Fibre Corp. has announced the appointment of **Robert D. Fleck** as manager, Quality Control. Formerly supervisor of the department, Mr. Fleck is a graduate of Drexel Institute.

Gordon B. Thayer is project manager of Dow Chemical International Ltd. S.A., Plastics Technical Service in Italy and Greece. Taking over in September, Mr. Thayer's responsibilities include planning and establishing technical service operations particularly as applied to customers of Dow Chimica Italiana S.p.A. He has been with the company since 1941.

Obituary

Herbert Weber, partner in the Aard Plastics Corp., Paterson, N. J., died last month. He was a past president of the Newark Section of the SPE.

PHILLIPS 66 MARLEX PLASTICS

BRIEFS

SALES SERVICE LABORATORY — REPORT 61-1

Our newsletter, introduced last year to a limited audience, is (we are pleased to announce) now being carried in most plastic trade magazines. Its purpose is to give us lab fellows a chance for a little broadcasting about our work . . . keeping MARLEX customers—and potential customers—up-to-date on new developments, our latest technical reports, and the like. From time to time we may do a little editorializing, too!*

High Density Ethylene Copolymers . . . After Two Busy Years!

Our ethylene-butene copolymers were first made commercially available in September, 1958. Since that time, these MARLEX 5000 resins have been a phenomenal success—especially for blow molding detergent bottles. They are also widely used for injection molding, fibre extrusion, wire and cable coating and non-container blow molding.

In physical appearance, temperature range (−180°F to 250°F), light stability, freedom from color and odor . . . the various melt index types of these new copolymer resins are similar to our original high density polyethylene (MARLEX 6000 resins). The main difference is in density (0.950 for the copolymers and 0.960 for the polyethylenes) and in the superior stress cracking resistance of the copolymers. They gain this desirable attribute at the expense of a nominal loss in tensile strength, rigidity, and resistance to permeation.

Stress cracking is a phenomenon not fully understood . . . although molecular weight, density, and molecular weight distribution are acknowledged as contributing factors. In all probability, the marked increase in both thermal and environmental stress cracking resistance exhibited by these new ethylene copolymers results from an optimum balance between density and molecular weight.

What all this boils down to is a wider choice of high density MARLEX resins. In applications requiring maximum rigidity and resistance to permeation, our 6000 resins are still unbeatable. Where these requirements are not uppermost, the new 5000 resins offer distinct advantages.

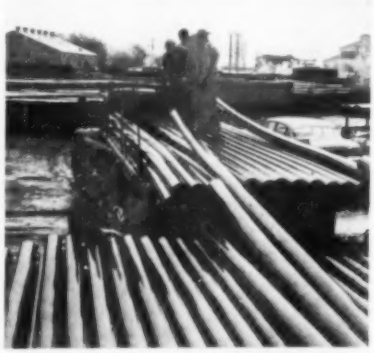
We have just published a new booklet on MARLEX High Density Ethylene Copolymers. It gives the complete story—charts, test data, physical characteristics, etc. If you haven't received a copy, let us know. Ask for Technical Information Bulletin #26.

Pipe and Conduit . . . Comments and New Data

Last year we talked of the potential demand for MARLEX pipe and conduit by utilities, municipalities, and industry (power, telephone, gas, water, and sewage). We have been developing this market for our TR-213 (a high density polyethylene tailored resin) and TR-212 (an ethylene copolymer tailored resin). Millions of pounds of MARLEX have gone into pipe and conduit in the last year—a very encouraging start.

Utilities and municipalities are tough customers . . . and very conscious of cost and overall performance. So far, we're proud to say MARLEX pipe and conduit resins have been enthusiastically received. Word gets around . . . and the lid is off.

How big is the potential market? It's almost hard to imagine. For those who like statistics, we offer some from the American Gas Association covering just a small part of the total market. The A.G.A. sees another 10 million gas customers in the next 10 years, each a user of 2" or smaller secondary distribution pipe. (Let's see, if each customer requires 150 feet of—ah . . . hum!) In addition, A.G.A. calculations of larger diameter primary distribution and gathering lines project some 520 miles per year for the next 10 years.



Rigid 5" MARLEX pipe and conduit like this is now being used for low-pressure gas, oil and water lines, power and telephone conduits, and sewer mains.

Our production department is geared to supply ever-increasing quantities of MARLEX pipe and conduit resin. In addition, we have just published some up-to-date information on pipe and conduit extrusion. This revised Technical Information Bulletin #15 is concerned with the external sizing technique of extruding high density MARLEX pipe. Let us know if you are interested.

New Resin for Coilable Pipe

Another important pipe item! We've just introduced a new high density pipe resin tailored for the coilable merchant pipe market. Pipe extruded from this new resin, called MARLEX TR-414, meets all requirements of Department of Commerce Standard, CS 197-60, for ASTM type III polyethylene, which uses a design hoop stress of 600 psi. It is approved by the National Sanitation Foundation, of course. Incidentally, TR-414 produces the most flexible ASTM type III pipe on the market. As a result, this pipe is ideal for sprinkler systems, potable water systems, farm water lines, and jet wells.

Breakthrough in The Auto Industry

Most manufacturers and material producers who make good in the auto industry manage to boast about it. We're no exception. In the 1961 models we have "scored big". By recent count our MARLEX resins are being used in about ten basic applications—such as seat side shields, side cowl panels, heater and defroster ducts, windshield washer bottles, glove boxes, and spring interleaf silencers. The total estimate for all high density polyethylene in 1961 cars and trucks is figured at close to six million pounds.

"Improved performance at equal or less cost" is almost an auto industry maxim for selecting something new. We feel their increasing use of MARLEX resins is a good testimonial.

*MARLEX is a trademark for Phillips family of olefin polymers.

PHILLIPS CHEMICAL COMPANY, *Bartlesville, Oklahoma*
A subsidiary of Phillips Petroleum Company

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East Providence 14, R. I.	New York 5, N. Y.	Akron 8, Ohio	Elmhurst, Ill.	Pasadena, Calif.	Dallas 25, Texas
GEneva 4-7600	Digby 4-3484	FRanklin 6-4126	TErrace 4-6600	MUrray 1-6997	EMerson 8-1358

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TECHNICAL MEETINGS CALENDAR

1961 REGIONAL TECHNICAL CONFERENCES (RETECS)

April 20—Plastics—A New Dimension in Buildings sponsored by Western New England Section with cooperation of Plastics in Buildings PAG, Springfield, Museum of Fine Arts, Springfield, Mass. Chairman: Robert W. Sherman, c/o Union Carbide Plastics Co., 410 Asylum St., Hartford 3, Conn.

May 9—Plastics in the Automotive Industry sponsored by Detroit Section with cooperation of Plastics in the Automotive Industry PAG, Detroit Mich. Co-Chairmen: John A. McPherson, c/o Underground Products Inc., 12801 Inkster St., Livonia, Mich., and John J. Doyle c/o Rohm & Haas Co., 20211 Greenfield St., Detroit 35, Mich.

June 14—Plastics in Packaging—Sheraton Mount Royal Hotel, Montreal, Quebec, Canada. Chairman: Ralph Noble, c/o Canadian Industries, Ltd., P.O. Box 10, Montreal, Quebec, Canada.

September 12—Plastics for Tooling sponsored by Central Indiana Section, Hotel Severin, Indianapolis, Ind. Chairman: Eugene C. Quear, c/o Delco-Remy Division, General Motors Corp., 2401 Columbus Ave., Anderson, Ind.

October 5—Plastics Foams sponsored by Buffalo Section. Section President: William Dunmyer, c/o The Carborundum Co., Building 71-1, Buffalo Ave., Niagara Falls, N. Y.

October 25—Plastics in Major Household Appliances sponsored by Kentuckian Section, Monogram Hall, Appliance Park, Louisville, Ky, Chairman: Ray E. Eshenaur, c/o General Electric Company, AP-5-249, Appliance Park, Louisville, Ky.

November 2-3—Plastics in Packaging and Engineering Exhibition on November 1, 2, 3. RETEC sponsored by North Texas Section and Exhibition by Section with cooperation of Southwestern Division Chapter, Society of Packaging and Handling Engineers, Sheraton-Dallas Hotel, Dallas, Tex. Chairman: Peter W. Kent, 3637 Mid Pines Drive, Dallas 29, Texas.

Offers of papers for presentation at these Regional Technical Conferences are invited. Please address offers to RETEC Chairman or Section President.

How SANTICIZER® 409 gives vinyl products high-priced properties at the lowest cost of any premium polymeric plasticizer

PERFORMANCE: SANTICIZER 409 *stays put.* Its compatibility-stability is superior, under highly humid conditions, particularly when formulated with heat-stabilizing epoxy plasticizers. SANTICIZER 409 stubbornly resists migration to polystyrene—and to both natural and synthetic rubbers—as well as extraction by solvents. Stability to light and heat is exceptional. There's hardly a trace of odor or color.

PROCESSING: The good solvating action of SANTICIZER 409 can boost your output, too. Promotes fast fusion and extrusion. Helps prevent "fisheyes," roughness, and pinholes.

PRICE: SANTICIZER 409—*at 4¢ to 6¢ per lb. LESS than other premium-quality polymerics*—imparts top-quality performance to many kinds of vinyl products.

PROOF: Try it . . . "on paper," in the laboratory, in the plant. Compare SANTICIZER 409 with *any* other polymeric plasticizer (price, properties, stability, ease of processing). You will see that SANTICIZER 409 gives *more profit per unit volume of vinyl compound.*

FACTS: Technical Bulletin PL-409 gives complete performance data—including specific details on how SANTICIZER 409 can help you make:

- **105° wire compound with exceptional electrical properties and retention of elongation.**
- **permanent, adhesive-backed film.**
- **migration-resistant, low-odor refrigerator gasketing.**

Monsanto

Monsanto Plasticizer Council . . . for plasticizer guidance that pays!

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Organic Chemicals Division
Plasticizer Council, Dept. 4410-V
St. Louis 66, Missouri

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SECTION NEWS

Eastern New England

Lecture Meetings Continue to Attract New Englanders

D. V. ROSATO
(Raytheon Co.)

A regular Lecture Meeting held January 31 at Armand's Beacon Terrace in Framingham, Mass., included the reading of papers by Mr. Edward A. Farrell, Lake Asbestos of Quebec, Ltd. discussing: Chrysotile Asbestos Fiber; Its Properties and Uses"; By Mr. Irving Skeist, Skeist Laboratories, "The Changing Technology of Adhesives" and at the Vinyl PAC meeting, by Mr. Melvin M. Gerson, Sandoz, Inc., "A Practical Dimension of Instrumentation in Solving Color Evaluation Problems", written by Mr. Gerson with Mr. Braverman, an associate at Sandoz.

Philadelphia

Active Program Planning A Feature of Philadelphia Section

GEORGE R. DEHOFF
(E. I. du Pont de Nemours & Co.)

There was a turnout of over 140 members and guests on February 28 for the second dual topic meeting of the '60-'61 year. While approximately half of the group attended a session on a Comparison of Epoxy and Polyester Resins the other half heard papers on Color Variation Problems in Vinyls.

R. J. Abelson of Shell Chemical Co. and J. J. Coleman of Atlas Powder Co. presented objective papers pointing out the merits and differences of Epoxy and Polyester Resins in reinforced applications. W. F. Carson of Rohm & Haas was Chairman.

J. P. Clancy of Lehigh Chemical Co. presided over the Vinyl Color session. Mr. M. M. Gerson and Mr. S. Braverman of Sandoz, Inc. discussed color instrumentation with direction being in the field of vinyls. Their discussion included a practical demonstration.

These meeting discussions are part of the carefully planned program of the Section which strives to cover a variety of phases of the industry throughout the year. The November 22 gathering was devoted to "Management" with two speakers covering existing laws of the Food and Drug Administration: Mr. Robert Stanfill, Philadelphia District Director of the Food and Drug Administration and Mr. Robert McFedries of Dow Chemical Co. This meeting was directed to those members having management responsibilities.

New York

Vinyls In Plastic Pipe

A. E. WHITNEY, JR.
(Goodyear Tire & Rubber Co.)

Built on the theme, Vinyls in Plastic Pipe, the New York Section's April 19th meeting will feature Mr. William E. Enright of the Glamorgan Pipe and Foundry Co., Plastics Division, and Mr. Jerome Schaul of the Lock Joint Pipe Co. Mr. Enright will discuss: "Sales, Marketing and Promotional Efforts", and Mr. Schaul, the technical phase of vinyl pipe.

Baltimore-Washington

Thermal Degradation on Polymers

S. P. PROSEN
(U.S. Naval Ordnance Laboratory)

On February 14, 1961, a talk entitled "Thermal Degradation on Polymers" was given by Dr. Samuel L. Madorsky of the National Bureau of Standards at the Dodge House in Washington, D. C.

This was generally a review of studies by Dr. Madorsky over the past several years on polymer behavior upon pyrolysis. All of the materials cited were linear polymers such as polyethylene, polymethyl methacrylate, polystyrene, etc.

Designing of Plastics

On February 16 Baltimore members were treated to an informative talk by Bob Peterson of duPont, who obviously was well qualified on his subject, "Designing of Plastics."

Florida

An Invitation and a Report From Florida

JACK GROSSCUP
(Modern Plastics, Industrial Materials)

Mr. Eugene Lux of the Lux Company, Miami, spoke at the January 16 meeting. A pioneer in the molded plastics industry, Mr. Lux pointed up the importance of: (1) Producing a product that is not only functional but also one that will sell. (2) Employing engineers who can read a specification. (3) Consultation with manufacturers in selection of proper materials. (4) Above all—making a profit.

Mr. Jim Hobbs of Hobbs Engineering, Miami, spoke briefly on the availability of retired and semi-retired talent in the Miami area.

Mr. George Light of Modern Plastics, Miami, related the history of this company's part in the development of Plexiglas windows for commercial aircraft.

At the February 20 meeting, the Honorable Judge Arthur Snyder spoke on Collections: The Legal Aspects and Methods Thereof. Plans were discussed for the May 25 tour of Cape Canaveral when the Section will be guests of the Air Force at Patrick Air Force Base.

After several months in first place, the Florida Section placed second as the Monterey, California, section moved to the top spot in the current membership drive.

S.P.E. members visiting Florida are reminded they are welcome to attend Florida Section meetings, 5:30 p.m., third Monday of the month, Carole's Restaurant, Hialeah, Florida.

Buffalo

Phenolic Molding Compounds

ANDREW J. HAMMERL
(Durez Plastics Div., Hooker Chemical Corp.)

Mr. E. F. Borro, Sr. of Durez Plastics Division, Hooker Chemical Corp., spoke at the February 13 meeting on phenolic molding compounds and their applications. Mr. Borro pointed out that despite the length of time phenolic molding compounds have been on the market, new applications are constantly arising for materials such as the high-impact glass-filled compounds.

Rochester

Kenneth Birch Machinery Paper Enthusiastically Received

J. T. BENT
(Eastman Chemical Products, Inc.)

Mr. Kenneth R. Birch, Manager of Electro Processes Company, Toronto, Canada, presented his paper, "Spark Erosion Machining of Mold Cavities" to forty-eight members at the February 13 meeting.

He traced the history of this method of machining, carefully pointed out usual electrical requirements, how the dielectric fluid controlled erosion, choice of electrode material—frequently brass—and the absence of pressure between the electrode and the work with the Sparkatron type of equipment.

St. Louis

"Labor Unions and You"

RICHARD H. KOEHRMANN
(International Shoe Co.)

Forty-seven members and guests attended the regular meeting at Holiday Inn, South on February 20, 1961. Following dinner, Attorney A. Carrol Gilpin of Hoffemeister, Trailes and Gilpin discussed the trends in the labor-management field and their application to the rights of management.

The membership committee reported that 19 new memberships are in process.

Newark

Extrusion Design and Application Seminar

R. E. CHRISTENSEN
(Union Carbide Plastics Co.)

The meeting on February 8 was at the Military Park Hotel with about two hundred members and guests in attendance. The program was a seminar sponsored by the Newark Section Extrusion PAC, moderated by Bruce Maddock, Development Scientist of Union Carbide Plastics Co. A lively and provocative evening evolved from presentations by the four speakers, as evidenced by the concluding panel discussion based on questions from the floor.

Mr. A. A. Kaufman, President of Prodex Corp., spoke on "Horsepower and Output Design Limitations."

The second speaker was Mr. W. R. Willert, Vice President of Frank W. Egan & Co., who spoke on "Principles and Methods of Venting Extruders."

Mr. John Badonsky, Chief Engineer of Waldron-Hartig Division, Midland-Ross Corp., spoke on "Long Metering Feed Screws."

Mr. E. E. Heston, Vice President of the Extruder Division, National Rubber Machinery Co., described "Variations of Valving." He classified the various methods of valving and demonstrated these with slides. Valving can be done at any part of the extruder, including at the hopper or inlet valving, at the center cylinder area, or at the front end.

How MOD-EPOX® liquefies viscous epoxy resins and "liquidates" some of the cost

PERFORMANCE: Reactive MOD-EPOX reduces epoxy resin viscosity as much as 75%, combines *chemically* in the curing to become part of the resin. This means you can use more filler, yet have faster flow, less entrapped air, fewer rejected finished parts. And final properties are actually *improved:*

FLEXURAL STRENGTH OF 4-PLY GLASS FIBER-EPOXY LAMINATES (ASTM D638)

FORMULATION:	Control	with MOD-EPOX
MOD-EPOX	—	25
liquid epoxy resin	100	100
diethylenetriamine	12	8
magnesium oxide (fluffy)	—	0.25
FLEXURAL STRENGTH:	**psi**	**psi**
original	42,400	48,400
ketone—40 hrs. @ room temp.	42,400	47,700
water—40 hrs. @ 100°C.	29,400	37,600
10% caustic—27 hrs. @ 100°C.	8,500	9,200

Epoxy resins modified with MOD-EPOX for better flow and lower cost show better dimensional stability—lower power factor—equivalent hardness—and higher adhesive strength (*shear bond strength of a standard epoxy adhesive increases more than 50%, steel-to-steel*).

ECONOMY: NOW . . . MOD-EPOX at 36¢/lb.* costs less than any grade or brand of epoxy resin, 50-75% less than most other modifiers . . . AND reduces the curing-agent requirements to about ⅔ of usual amounts.

FACTS: Technical Bulletin PL-313 gives complete performance data—including specific details on how MOD-EPOX can help you make:

- **easy-handling electronic potting compounds.**
- **low-cost auto-body-solder formulations.**
- **high-strength casting and encapsulating compounds.**
- **tenacious adhesives for metals and glass.**

*T/L and C/L, F. O. B. Monsanto, Illinois

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Pioneer Valley

Spray Painting Plastics

ROGER JOHNSTON
(Foster-Grant Co., Inc.)

Mr. Ray Sebetto, of Conforming Matrix, using slides and films, gave us a complete story of spray painting by automatic and semi-automatic equipment. These arrangements produce even coats and are very fast. Some details were then discussed. Mask pressures of 45-lb. are used. With baffles on the mask two or more colors can be sprayed. Each type of equipment, whether work moving or gun moving, has its definite place.

The variables which require closest attention are viscosity of paint, fluid pressure, atomization air and amount of air. With careful control and correct design of masks automatic spray painting is an efficient finishing tool.

Kentuckiana

Reinforced Plastics, Polymer Research . . . Considered at Section Meetings

GEORGE A. POLK
(General Electric Co.)

The January 18 meeting was held at Bill Boland's Dining Room.

The speaker was Mr. R. H. Sonnehorn, Manager of Plastics Development, Owens Corning Glass Co. Subject: Reinforced Plastics, with emphasis on glass reinforcement. The various types of glass reinforcement were related to their applications. Also covered, in an entertaining manner, was the molding of reinforced plastics, both preform and premix. His remarks were appropriately illustrated.

Dr. Edward E. Bostic of the General Electric Company's Research Laboratory was guest speaker at the February meeting. His subject was "New Areas of Polymer Research and Application."

Ontario

Extension Course Certificates Awarded

H. A. SHURE
(Naugatuck Chemical Co., Ltd.)

The two year extension course on plastics at the University of Toronto was the first of its kind in North America, having been inaugurated by the University under sponsorship of this Section. Presentation of attendance certificates took place February 21 at the University of Toronto.

Embracing the fundamentals and technology of the plastics industry, the course attracted enrollment of over 250 during the two year period. Of these, 100 received certificates indicating that they attended 80% of the lectures. For those who started the course in the second year, attendance credit has been given so that they will qualify for a certificate on completion of their first year.

Mr. James E. Parkhill, the course consultant, states that the 1961/62 session will commence in September 1961 under the directorship of Professor W. G. MacElhinney, MASc.

Howard Yeates, "Acrylic" Pioneer, Featured Meeting Speaker

Seventy people attended the lecture on "The Vacuum Foaming of Acrylics" by Howard Yeates of English Plastics Limited, Brampton, Ontario. Howard Yeates was one of the first men in Canada to vacuum foam acrylics. He traced the fascinating history of acrylics from its earliest days through to its present day usage. Sample moldings of unusual designs and shapes were shown.

Miami Valley

Clarence Parks Discusses Rigid PVC

ROGER A. HOUSTON
(Recto Molded Products, Inc.)

At the February meeting Mr. Clarence Parks, Manager of Production Development of the B. F. Goodrich Company was the speaker. Fifty members and guests were on hand at the Eaton Manor in Hamilton, Ohio.

Mr. Parks brought to his subject, "Rigid PVC, Processing, Properties and Applications", a wealth of information clearly the result of his intimate knowledge, derived from his own experiences in the early development of this material.

Western New England

Award Winner Speaks at February Meeting

MERLIN L. EVANS
(Plax Corp.)

Richard M. Bell of Lakeville Precision Molding, Inc., Lakeville, Conn., discussed "Precision Molded Plastics Parts" at the February 1 meeting held at Betty's Town House in Agawam Mass. Mr. Bell is the winner of the Copper and Brass Achievement Award for the outstanding achievement in brass, 1960.

Cleveland

'61 Business Outlook Reviewed

E. K. McCLELLAN
(Eastman Chemical Products, Inc.)

The January meeting was held Monday, January 16, at Pesano's Restaurant, Cleveland, Ohio, with 54 members and guests on hand to hear Mr. Fred O. Kiel of the Federal Reserve Bank of Cleveland speak on "Business Otulook for 1961". Mr. Kiel's talk was well illustrated by various graphs and indicated that business in general can look forward to better times soon.

A second talk was given by Mr. Richard Rybak of R and K Plastic Industries on the subject of "The Custom Molder Looks at New Materials".

Central Indiana

PAC Activities Reviewed

JAMES T. MILLS
(Hyaline Plastics Corp.)

The January 31 dinner meeting was attended by 40 members and guests.

The program featured Barney Hitchcock, PAC Chairman for the Section. He reviewed the Committee's activities during the past several months as they investigated practical and theoretical aspects of heating cylinders for injection molding machines.

An added feature of the program was a talk by Mr. F. M. Adair, Molding Machinery Engineer, for Western Electric, on the Past, Present, and Future of Preplasticizers for Injection molding. Mr. Adair discussed plunger preplasticizers, single and double screw machines, and the new rotating spreader arrangement developed by DuPont.

Milwaukee

Record Turnout for Williamson Talk

C. H. STRONG
(Union Carbide Plastics Co.)

The January 17 meeting, with an attendance of 90 people, was one of the largest we have had! Held at the Bavarian Club, the guest speaker was Dr. Charles W. Williamson, Group Leader of Injection Molding, Sales Service Dept., Esso Research & Development, ENJAY Laboratories. Dr. Williamson discussed the chemistry

of the polypropylene polymer in regard to its effect on molding conditions and past design.

He spent considerable time on the effect of crystallinity on the specific heat of the materials and its effect on processing temperature, as well as other points of interest.

Golden Gate

Screw Plasticising Injection Presses

MIKE RABIN
(Transparent Products Corp.)

At the regular monthly meeting February 24, at the International Inn, 35 members and guests were present as Mr. Brant Newsom, President, introduced the guest speaker, Mr. Jack G. Fuller, Sales Manager, of Krauss-Maffei International, Ankerwerk International.

Mr. Fuller spoke about the general acceptance in Europe of the German-manufactured reciprocating screw plasticizing injection molding machine and its potential in this country.

Southern California

Student Visitors Hear "Nylon" Panel Discussion

L. E. TALLMAN
(The Dow Chemical Co.)

Student Visitation Day was held during the February 2 meeting at which time 108 members and guests were present. A panel discussion on Nylon proved interesting to the students as well as the membership.

We anticipated professors and students from six local universities but, unfortunately, semester examinations reduced the school representation to four. From the University of Southern California—Dr. E. G. Partridge, and students Edward Agrlicska and James Love; University of California, Los Angeles—students Ray Orloski and Paul Sleezer; Los Angeles State College—Dr. Jaffee, and students Fred Martin and John Granger; Los Angeles Trade-Tech—Neil T. Moore, head of department, and A. V. Keller, plastic instructor; night school plastics instructor Seymour Schwartz.

SPI is sponsoring a plastics night school one night a week for eight months at Los Angeles Trade-Tech. These classes last for 2-½ hours and cover every phase of plastics from raw materials to end products, and many students at college level watch the program and attend the classes of their choice.

How SANTICIZER® 160 speeds processing and cuts costs of nonstaining PVC film and sheeting

PERFORMANCE: No other plasticizer can make film, sheeting, and floor covering so *STAIN-SAFE*—virtually impervious to asphalt, tar, grease, mustard, catsup, coffee, and other stainmakers. SANTICIZER 160 (butyl benzyl phthalate) also imparts toughness, high gloss, *and outstanding tear strength and dimensional stability.*

PROCESSING: Quick-fusing SANTICIZER 160 speeds Banbury mixing, milling, and calendering—*at lower processing temperatures.*

ECONOMY: SANTICIZER 160 is one of the lowest-priced primary plasticizers for vinyls. With its high tolerance for fillers and its high compatibility—*150 PHR for poly(vinyl chloride), 75 PHR for poly(vinyl acetate)*—it offers compounders savings on material, savings on formulation.

"TAILORED" BLENDS: In large-volume applications, when several plasticizers are used together in a fixed ratio for optimum performance, Monsanto can usually *custom blend* them to your specifications . . . to reduce your storage-facility requirements; eliminate mixing error or variation; and reduce inventory requirements, ordering costs, and production expense.

FACTS: Technical Bulletin PL-160 gives complete performance data—including specific details on how SANTICIZER 160 *also* can help you make:

- **lower-cure-temperature plastisols and organosols.**
- **high-gloss, water-resistant lacquers.**
- **economical vinyl chloride-vinyl acetate emulsions.**

Monsanto

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MONSANTO CHEMICAL COMPANY
Organic Chemicals Division
Plasticizer Council, Dept. 4412-V
St. Louis 66, Missouri

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PLASTICS AROUND THE WORLD

This month's column has been made possible through the contributions of these abstracters:
Hans Mayer (Industries Des Plastiques Modernes)
Alfred L. Alk (Poliplasti and Materie Plastiche)
T. Wold (Danish Plastics)
G. Gruenwald (Kunststoff-Rundschau and Kunststoffe and Plaste Un Kautschuk)
L. S. Buchoff (Materials in Design Engineering)
Philip G. Fleming (Mechanical Engineering)
Walter A. Gammel, Sr. (ASTM Bulletin)

Germany

PLASTE UND KAUTSCHUK

JUNE 1960

Study of Filler Distribution in Silicone Rubber Using X-Ray Small Angle Dispersion—pp 298-300

X-Ray small angle dispersion measurement is a particularly well suited method for the determination of physical filler parameters. Contrary to other methods it enables an observation of the filler dispersion outside and inside the rubber mixture without much preparative expense.
The distribution of colloidal silicic acid (aerosil) in silicone rubber was studied by the authors. It was shown that filler particles do not change during admixture. However, an extension of the surface of the filler particles is obtained by rubber vulcanization.

SEPTEMBER 1960

Rubber-Based Adhesives—pp 432-434

After a short description of the properties of rubber-based adhesives conditions are dealt with which must be observed in the preparation of adhesive bonds. They are followed by a description of bonding methods and consideration on bonding errors and their suppression. A more detailed account is given on "Hard Rubber Material, White" and "Contact Adhesive No. 2/100." Synthesis, properties, processing and application are described.

OCTOBER 1960

Influence of Air Humidity on the Surface Resistance of Plastics—pp 480-486

Under the influence of high relative air humidity the surface resistance of plastics can lie far below values indicated in literature. This is important when using plastics as insulating materials in electrical and, particularly, electrometrical equipment under severe climatic conditions. It is shown that suitable materials and an appropriate design of insulators can considerably reduce the unfavourable influence produced by high air humidity.

Graft Copolymerization. Part III: Other than Radiation-Chemical Methods of Graft Copolymerization—pp 489-492

After a description of the fundamentals of graft copolymerization by chemical stimulation, the author deals with unsaturated polymer stimulation, cross-linked graft copolymers and grafting by addition and condensation reactions, with special regard to unsaturated polymers.

KUNSTSTOFF-RUNDSCHAU

OCTOBER 1960

Polyolefin Film and Sheet Production—pp 474-480

This article represents another very thorough description of polyolefin processing. This time, the same author of last month's paper on Blow Molding points out details in Film Blowing, and Film and Sheet Casting. He also compares their advantages and disadvantages and includes the much less popular calendering of films.

NOVEMBER 1960

Plastics Analysis—Collected from the 1959 Literature—pp 523-529

As in previous years, the author again compiled from the international literature of 1959 data pertaining to the chemical and spectroscopical analysis as well as to electrical, physico-chemical and mechanical measurements on plastics, natural high polymers and their products. This first part takes into consideration 142 publications.

DECEMBER 1960

Processing of Plastics With Calenders—pp 569-573

Calendering has obtained wide recognition in making films and thin sheets due to its economics. However, a high viscosity and a wide temperature range under processing conditions are requirements for these plastics.

KUNSTSTOFFE

OCTOBER 1960

The Effect of Water on the Bursting Strength of Rigid PVC Pipes—pp 537-540

Moisture absorption and creep strength curves were determined for a number of rigid PVC pipes at 60°C.

Emulsion Polymerization Using A Polyacrolein Sulphurous Acid Solution As An Emulsifier—pp 568-570

A new type of macromolecular emulsifying agent which consists of solutions of homo- or copolymers of acrolein in aqueous sulphurous acid is described.

NOVEMBER 1960

Determination of the Degree of Cure in Thermosetting Materials—pp 598-605

Conventional test methods fail when used to determine the degree of curing of moldings from which samples cannot be taken because of size, shape or other considerations. The boiling test does not give sufficient indication of the degree of curing. Better results are obtained if the amount of soluble matter is determined and a comparison is made between the amount in the original resin and in the finished molding. The difference gives the degree of cure.

Use of Electronic Tearing Instruments for Determining Properties of Plastic Film—pp 618-622

The author describes a new instrument which enables force-deformation curves to be produced even in plastic film which is multiaxially stressed by impact and tension.

USA

MATERIALS IN DESIGN ENGINEERING

OCTOBER 1960

The Polypropylene Hinge—pp 117-

Continued on page 392

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ASTM BULLETIN

OCTOBER 1960

Flexural and Impact Variations of Phenolic Moldings: A Statistical Round-Robin Study—pp 35-37

To standardize on specific methods of specimen preparation, a round-robin was undertaken to compare compression vs transfer molded specimens and establish molding procedures for each.

Denmark

PLASTIC

NOVEMBER 1960

Danish Made 60 mm Extruder—pp 340-341

"Danish Plastics" the company that won a world-wide reputation for its bottle blowing machine "Blow-O-Matic" has just marketed a 60 mm extruder. A big feature is said to be a step-less hydraulic speed control which can vary the screw speed from zero to 90 RPM making it possible to extrude small to large cross sections. A detailed description of the construction is included in the article.

France

INDUSTRIES DES PLASTIQUES MODERNES

DECEMBER 1960

Injection Molding with Screw Extruders—

The method of injection molding of preplasticized materials is the outcome of a long chain of technical developments since the introduction of the first injection molding machines. Step by step the improvements in the preparation of the molding material is retraced, describing the addition of heating torpedoes to the cylinder, the separate extrusion setup for preplasticizing and finally the extrusion of the material directly into the mold. Advantages and disadvantages of applications for various materials and finished articles are weighed against each other.

Italy

POLIPLASTI

NOVEMBER-DECEMBER 1960

The Screw Press in Thermoplastic Injection Molding—pp 28-33

The idea of applying the principle of screw extrusion to injection molding was first documented in 1927 by a German patent application. It remained dormant until 1943 when a series of patents covering the process were issued. The first machine was presented in 1949. Actually, there are many machines and little literature. The operation substitutes a screw extruder for the usual injection complex. The raw material is plasticized in the heated extruder barrel and delivered to a chamber in front of the screw which is formed as the screw is slowly retracted from the molding section. During the injection cycle, a hydraulic ram forces the extruder screw forward injecting the plasticized melt in the usual fashion. Only 2 or 3 times the weight of the shot is maintained in the melt chamber, and very close control of the temperatures can be kept.

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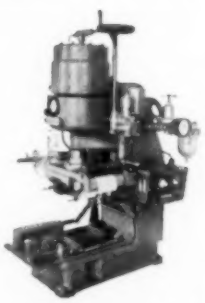

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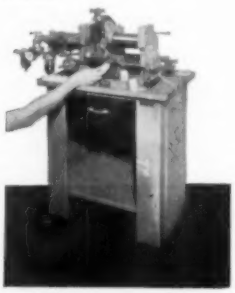

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Event: Annual Student Night of SPE's Eastern New England Section

Date: Tuesday, April 25, 1961

Place: Armand's Beacon Terrace
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Speaker: An outstanding representative of Notre Dame University

This meeting was erroneously scheduled in the February issue of the Journal for March 28. Please note the new date and speaker.

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PLASTICS ENGINEER

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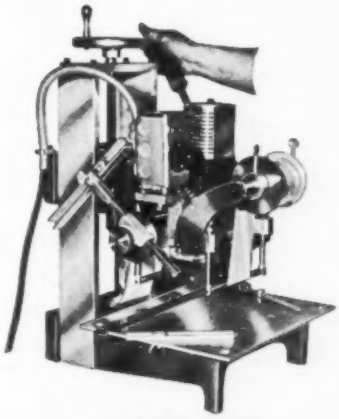

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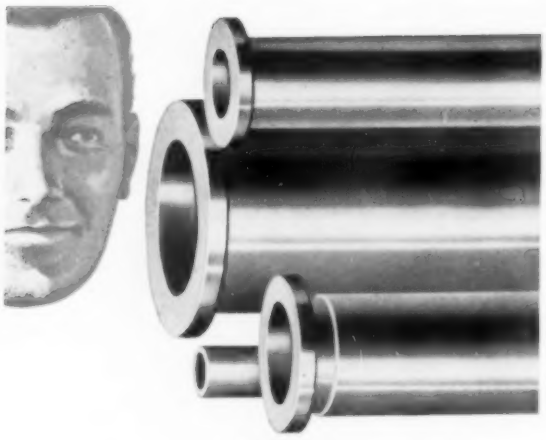

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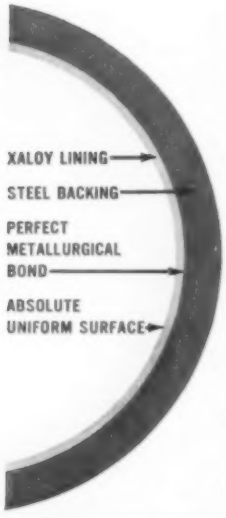

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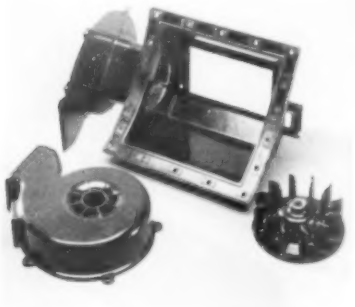

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Note, too, how economy begets economy. Very few assembly operations. Few rejects, because these phenolic parts can't get bent and won't warp. No balancing needed in the blower wheel, because concentricity is molded in. Wobble is much less than could be achieved at low cost in a metal wheel.

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The different polyester

Cutting across the currents and countercurrents of talk about reinforced polyester plastics are two incontrovertible facts:

1. You can get a polyester molding material that's *inherently and permanently self-extinguishing*.
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So much for chemistry. The craze resistance takes longer to explain, but matched-die molders know they can count on it for structural shapes that must undergo a 90-minute bake at 350°F.

Superimpose these two truths on the other advantages of strong, lightweight polyester construction, and you can appreciate why Hetron is helping so many designers give shape to new ideas. This luggage pod for a jet airliner is one case in point. Others include 65-foot radomes, factory skylights, large boat hulls, outboard-motor shrouds, chemical ducts and vessels, transformer housings, heavy-duty switch-gear components.

If you'd like to know more about this versatile material, check the coupon for designer's Hetron data file.

For more information on Durez materials mentioned above, check here:

- ☐ Phenolic molding compounds (8-page Bulletin D400)
- ☐ "Durez Plastics News" (a review of current plastics applications, mailed bimonthly)
- ☐ Hetron polyester resin (data file and list of fabricators)

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GERING Thermoplastic MOLDING COMPOUNDS

quality formulated to perform as required!

Roaring down the Atlantic test range or blasting off from the living room floor, true missile performance depends on the accurate behavior of individual components. That's where Gering's expert ability to formulate superior thermoplastic Molding Compounds comes in. Whether the end use is a vinyl jacketing compound that helps trigger a giant ICBM into space or an impact styrene toy replica, quality Gering Molding Compounds perform to perfection. Extensive laboratory and production facilities enable Gering to produce to your most exacting specifications — including flame-retardant, non-toxic, semi-conductive and other special formulations. And with these complete facilities at your service, your most demanding custom compounding requirements can always be met. Tell us your specific needs. We'll be happy to submit a recommendation at no obligation. Write today for information.

• Polyethylene • Vinyl • Styrene • Impact Styrene
• Acetate • Nylon • Acrylic • Styrene Copolymer • Butyrate

Cable Address: GERING • TWX Cranford, N.J. 137 • Sales Offices: 5143 Diversey Ave., Chicago 39, Ill.
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GERING
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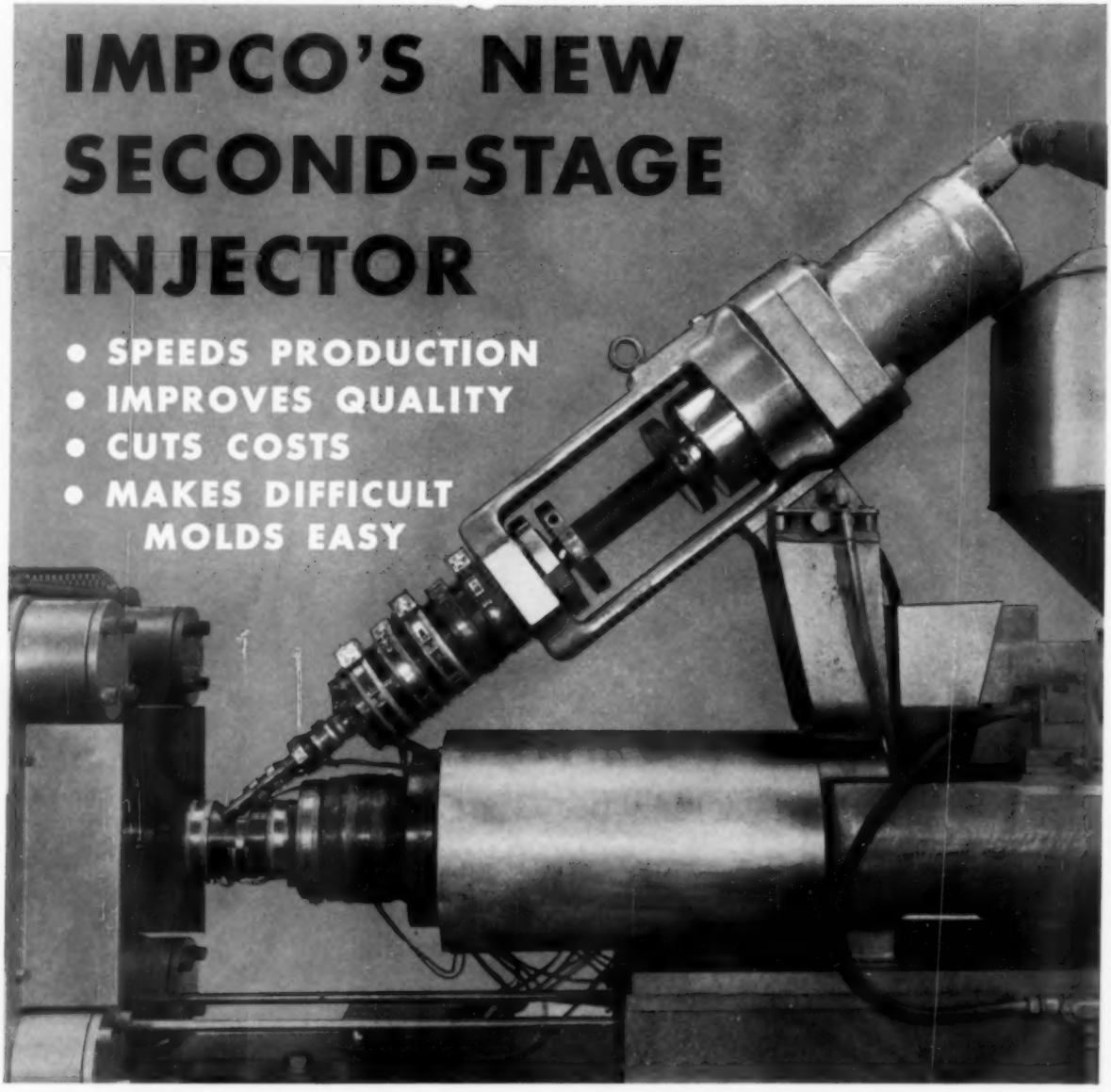
division of STUDEBAKER-PACKARD CORP.,
Kenilworth, N.J.

IMPCO'S NEW SECOND-STAGE INJECTOR



- SPEEDS PRODUCTION
- IMPROVES QUALITY
- CUTS COSTS
- MAKES DIFFICULT MOLDS EASY

The Second Stage Injector was designed to increase the effective operation of any Impco Injection Molding Machine now in service. It is also now available as standard equipment on new Impco machines. Its use gives you:

- Raw material savings
- Increased capacity
- Reduced molding pressures
- Increased mold area
- Simplified nylon molding
- Fewer rejects

Ask for Bulletin P-127 for more information.

IMPCO®

IMPROVED MACHINERY INC.
NASHUA, NEW HAMPSHIRE

MANUFACTURERS OF IMPCO PLASTIC MOLDING MACHINES